NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 1005

CORRELATION BETWEEN STRENGTH PROPERTIES IN STANDARD TEST SPECIMENS AND MOLDED PHENOLIC PARTS

By P. S. Turner and R. H. Thomason
National Bureau of Standards

Washington
May 1946

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SUMMARY

This report describes an investigation of the tensile, flexural, and impact properties of 10 selected types of phenolic molding materials. The materials were studied to see in what ways and to what extent their properties satisfy some assumptions on which the theory of strength of materials is based: namely, (a) isotropy, (b) linear stress-strain relationship for small strains, and (c) homogeneity. The effect of changing the dimensions of tensile and flexural specimens and the span-depth ratio in flexural tests were studied. The strengths of molded boxes and flexural specimens cut from the boxes were compared with results of tests on standard test specimens molded from the respective materials.

The nonuniformity of a material, which is indicated by the coefficient of variation, affects the results of tests made with specimens of different sizes and tests with different methods of loading. The strength values were found to depend on the relationship between size and shape of the molded specimen and size and shape of the fillers. The most significant variations observed within a diversified group of materials were found to depend on the orientation of fibrous fillers. Of secondary importance was the dependence of the variability of test results on the pieces of filler incorporated into the molding powder as well as on the size of the piece.

Static breaking strength tests on boxes molded from six representative phenolic materials correlated well with falling-ball impact tests on specimens cut from molded flat sheets. Good correlation was obtained with Izod impact tests on standard test specimens prepared from the molding materials. The static breaking strengths of the boxes do not correlate with the results of tensile or flexural tests on standard specimens.

INTRODUCTION

No thorough investigation of the relationships between the strengths of molded plastic articles and strength data on their materials has been reported. Most of the available data on the strength properties of molded phenolic plastics have been obtained with standard test specimens and standard methods of test. Specific data of this type, obtained in accordance with test methods established by the American Society for Testing Materials, are published in manufacturers' data books, for example, references 1 and 2. These sources acknowledge that a "molding material, which on standard test pieces appears superior, may show up in actual production as being even inferior to another material which on standard test pieces reveals a lower order of desirable properties" (reference 1). These discrepancies are further attributed to such factors as peculiarities in mold design, size and shape of the molded article, and variations in molding conditions, but not to inherent differences in the materials or to selective characteristics of the standard test specimens.

This investigation of the strengths of molded parts and standard test specimens, conducted at the National Bureau of Standards, was sponsored by and conducted with the financial assistance of the National Advisory Committee for Aeronautics.

The molding materials for this investigation were supplied by the Bakelite Corporation and the Monsanto Chemical Company, Flat plates molded in 1/8- and 1/4-inch thicknesses were furnished by the Bakelite Corporation and boxes were molded of the same materials by the General Electric Company, Plastics Division. The cooperation of these firms has made possible this exploration of the nebulous region between standard tests and structural performance and is gratefully acknowledged.

MATERIALS AND PREPARATION OF TEST SPECIMENS

The materials used in this investigation are listed in table I. Flat sheets were molded from the Bakelite phenolic molding materials by the Bakelite Corporation. Rectangular boxes were molded from the same compositions by the General Electric Company. Moldings prepared at the National Bureau of Standards included: dumbbell tensile specimens in accordance with type I of Method No. 1011 of Federal Specification L-P-406a; rectangular bars, 1 inch wide and 5 inches long;

bars 1/2 by 5 inches for impact specimens; cylinders, 2 inches in diameter and approximately 1 inch in length; and disks, 4 inches in diameter and of various thicknesses. The molding conditions are given in table II.

The specimens molded at the Bureau of Standards were prepared with fully positive hand molds heated by conduction from steam-heated platens. The molding was done with a 50-ton-capacity semi-automatic press. Preforms were prepared in the same molds that were used for the particular specimen. Some of the materials did not produce good preforms at room temperature with the pressure available or permissible for the particular mold. Preforms of these materials were made at somewhat elevated temperatures (see table II) with a hand-operated hydraulic press of 18-ton capacity. The platens were electrically heated and thermostatically controlled.

All machined test specimens were prepared at the National Bureau of Standards. The tensile specimens were milled with a machine having a cam-operated milling fixture for duplicating the desired contour.

TEST PROCEDURES AND EQUIPMENT

Tensile Tests

Tensile tests were made in accordance with Method No. 1011 of Federal Specification L-P-406a, except that the rate of separation of the grips was maintained at 0.05 inch per minute and the profile of the specimen specified for thicknesses of 1/4 inch or less was used for all tensile tests. Strains were measured with a Southwark-Peters plastics extensometer, Model No. PS-6, and an autographic stress-strain recorder.[1] The tensile tests were made on the 0- to 2400-pound range of a 60,000-pound-capacity universal hydraulic testing machine.

Flexural Tests

Flexural tests were conducted at rate of loading specified in Method No. 1031 of Federal Specification L-P-406a

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[1]These strain gages and the recording equipment are described in Bulletin No. 162 issued by the Baldwin Locomotive Works, Baldwin Southwark Division, Philadelphia, Pa.

for obtaining load-deflection data. Calculations of flexural strength, maximum fiber stress, and modulus of elasticity were made as described in Method No. 1031.

In the tests reported in tables III and IV approximate span-depth ratios were obtained with support and pressure pieces having loading edges rounded to 1/8-inch radii. This jig, together with a notched spacing and centering plate, provided adjustment at a limited number of positions. Subsequent tests were made with self-centering continuously variable jigs of the type shown in figure 1 with attachments for obtaining load-deflection data. The deflections were measured with Southwark-Peters plastics extensometers, Models PS-6 and PS-7, and an autographic stress-strain recorder. The pressure and support pieces of the jig which was used for spans of 2 inches or less, shown in figure 1, were rounded to radii of 1/32 inch; those of a larger jig of the same type which was used for spans greater than 2 inches had radii of 1/8 inch.

Specimens used in the study of the effect of span-depth ratio were first broken at the largest span. The remaining pieces were used for tests at shorter spans. Care was taken to insure that points highly stressed in the first test did not coincide with points of maximum stress in subsequent tests. Comparisons with specimens which had not been used previously indicated that the portions of the specimens which were used again had not been damaged in the first tests. This method of sampling was used to avoid effects of thickness and cure which might affect the results.

The flexural tests were made on the 0- to 2400-pound range of a 60,000-pound capacity universal hydraulic testing machine and on the 0- to 240- and 0- to 1200-pound ranges of a 2400-pound-capacity machine.

Izod Impact Tests

The standard Izod impact test was conducted in accordance with Method No. 1071 of Federal Specification L-P-406a on specimens having machined notches. The molded 1/2- by 1/2- by 5-inch bars were cut in half to make two impact specimens. One-half of each bar was notched in the direction of the molding ram motion and the other half of each bar was notched in the direction perpendicular to the ram motion. The tests were made with a pendulum-type impact-testing machine of 4 foot-pound capacity, using the 2- and 4-foot-pound ranges.

A correction for the energy absorbed in tossing the broken pieces of the specimens was obtained as follows: The broken pieces of the specimens were fitted together and subjected to a second impact. This tossing energy was corrected for friction and windage. It was assumed that the energies imparted to the severed end of the specimen were proportional to the unexpended energies after the Izod and tossing tests. A portion of the tossing energy proportional to the unexpended energy in the Izod test was subtracted from the Izod impact value.

Falling-Ball Impact Tests

Falling-ball progressive-repeated impact tests, similar to Method No. 1074 of Federal Specification L-P-406a, were conducted on $3\frac{1}{2}$- by $4\frac{1}{2}$-inch rectangular sections cut from the molded flat sheets. Preliminary tests were made on 4-inch-diameter disks of various thicknesses supported on a cast-iron-pipe cap.

The equipment used for testing the rectangular sections is shown in figure 2. The specimens were mounted in a hardwood frame which rested on a flat steel plate. The frame provided a 1/8-inch-wide supporting area at the edges. A 1/2-pound steel ball was used for tests on 1/8-inch-thick sheet material and the molded disks; 1/2- and 2-pound balls were used for testing 1/4-inch-thick sheet material.

The height of fall was increased in steps of 1 inch starting with the 1-inch height, until complete failure occurred. The energy to crack the specimens also was noted.

Impact - Flexural Test

Flexural specimens 1/2 inch wide, which were machined from the 1/8-inch-thick molded flat sheets, were struck at the center of a 3-inch span with a ball weighing 0.15 pound. The equipment was essentially the same as that shown in figure 2 except that a flexural-test jig (see fig. 1) with support pieces rounded to 1/8-inch radii was substituted for the wooden frame. The height of fall was adjusted by successive high-low approximations so as to obtain the height of fall which would crack but not break apart the specimens of a specific material with a single blow. A majority of the specimens received impacts close to the energy required to crack the specimen. All specimens which were not completely broken by the impact were subjected to a flexural test at a

span-depth ratio of 8:1 with the load applied at the point of impact. The flexural strengths were plotted against the impact energies applied to the individual specimens.

Tests on Molded Boxes

Breaking-strength tests were conducted on molded boxes using a plunger having a hemispherical end of 5/8-inch radius, as shown in figure 3. The rate of travel of the plunger relative to the base of the boxes was 0.05 inch per minute. The loads were applied in three ways: (1) at the molded hole; (2) at a point on the bottom symmetrically located on the diagonal with respect to the center and the molded hole; and (3) at the latter point through a rubber cushion. The load was not applied at the center of the bottom because of a deeply indented mold number located at that critical point. The rubber cushion was a No. 7 rubber stopper placed with the larger diameter face bearing on the surface of the box. (See fig. 3.) No attempt was made to analyze the stresses set up in the boxes by the loads applied.

Conditioning.- All the specimens were conditioned for at least 48 hours at 25° C (77° F) and 50 percent relative humidity and were tested in the conditioned atmosphere.

Statistical Analysis

The coefficient of variation which is used as a measure of the variability of the materials, is based on the most likely estimate of the standard deviation of the parent population (reference 3, p. 145). It is calculated according to the formula:

$$V = \frac{\sqrt{\sum (d_i)^2 / (n - 1)}}{\text{Average}} \times 100$$

where

V coefficient of variation in percent

d_i deviation of the individual result "i" from the average

n number of test results

The standard error of the average was calculated according to the formula:

$$S.E. = \sqrt{\Sigma \, (d_i)^2 \, / \, n(n - 1)}$$

The standard error for the difference between two averages was calculated according to the formula:

$$S.E._{AB} = \sqrt{S.E._A{}^2 + S.E._B{}^2}$$

The difference between two averages is considered to be significant if it equals or exceeds 3 times $S.E._{AB}$.

RESULTS OF TESTS AND DISCUSSION

Anisotropy of Molded Phenolic Plastics

Standard test specimens and standard methods of test do not, as a general rule, take cognizance of the possibility that molded phenolic plastics may be nonistropic in the three-dimensional sense. It has been reported (reference 4, p. 84) that molded thermosetting plastics are generally isotropic.

Visual examination of molded articles of various sizes and shapes indicates that in thin sections long fibers of the filler are oriented in planes parallel to the molded surfaces. In thick sections the fibers tend to be oriented in planes perpendicular to the direction of flow in the molding. Peculiar orientations are found around inserts and at abrupt changes in section thickness. Fibers in gradual changes of section are oriented around the contour of the part. Sketches illustrating the orientation of fibers are shown in figure 4.

Differences in the directional properties of the various phenolic molding materials in the form of molded cylinders, 2 inches in diameter and approximately 1 inch in length, were investigated. Sections cut from these cylinders were of uniform appearance when sanded except that the orientation of long fibers was visible. Fibers in the interior of the cylinders were oriented at random in planes perpendicular to the axis of the cylinders, the direction of the ram motion. Fibers near the surface were oriented parallel to the molded surface.

Flexural specimens of approximately uniform size were cut from the cylinders parallel and perpendicular, respectively, to the axis. Specimens cut from the circular faces were discarded. Rectangular specimens were machined and sanded to uniform thickness within ±0.001 inch.

The results of the flexural strength tests are presented in table III. All the specimens cut with their long axis parallel to the direction of the ram motion failed with typically brittle breaks. The specimens of the long fiber materials cut with their long axis perpendicular to the ram motion broke with "green stick breaks."

The ratio of the flexural strength of specimens cut parallel and perpendicular, respectively, to the axis of the cylinder is used as an index of isotropy. The variation of this index with bulk factor of the powder (see footnote of table I) is shown graphically in figure 5. The bulk factor is roughly a measure of the size and the shape of the filler particles.

Tensile and Flexural Properties of Phenolic Plastics

Variation of flexural strength with span-depth ratio. The strength of a structure made of a brittle material usually is determined in service by resistance to bending, alone or in combination with axial loading (reference 5, p. 25). It is generally recognized that the flexural strength (modulus of rupture) varies with the material, the form of the section, the method and rate of loading, the span-depth ratio, and, in the case of fibrous materials such as wood, upon the size of the piece. The effect of span-depth ratio on the strength of brittle materials - for example, cast iron and plaster - is slight except for ratios less than 10 (reference 6, pp. 103 and 106).

Few data on the variation of flexural strength with span-depth ratio have been reported for plastics although different specifications require different ratios for testing. Federal Specification L-P-406a requires a minimum span-depth ratio of 16:1. The flexural strength data published in the manufacturers' data books have been determined at a span-depth ratio of 8:1 in accordance with A.S.T.M. methods.

The variation of flexural strength with span-depth ratio obtained on molded specimens of 10 phenolic molding materials is given in table IV. The depth of the beam in these tests was the molded thickness of the sheet. Curves for BM-45, BM-120, and R-6565, which showed statistically significant variations with span-depth ratio, and for BM-250, which showed practically no change, are shown in figure 6. The asbestos-filled material, BM-250, and the mica-filled material, Resinox 7013, show the least variation with span-depth ratio.

The materials containing large pieces of filler, such as those containing tire cord or macerated fabric, frequently broke at points some distance from the center of the beam. These failures occurred at the junctures of large pieces of filler. The results obtained with those materials were too variable to show a significant variation with span-depth ratio with the number of specimens used.

Although no two materials show the same quantitative variation with span-depth ratio, the flexural strengths of the molded and laminated plastics are usually greater for smaller ratios.

The large deflections obtained in the flexural tests of some plastics at large span-depth ratios introduce considerable error into the calculation of the bending moment. The reactions at the support pieces are no longer parallel to the applied load. The component of the moment produced by the sidewise thrust of the support pieces is not considered in the method of calculating prescribed by the Federal and A.S.T.M. specifications. Also when large deflections occur, the specimen may slip and increase the actual span length. The magnitude of these errors would be less in tests at a span-depth ratio of 8:1 than at a ratio of 16:1.

Effect of varying the dimensions of specimens on flexural strength.- The results of flexural tests on specimens cut from flat sheets and on molded bars are listed in table V. Specimens were prepared from the flat sheets in three widths for both 1/8- and 1/4-inch thicknesses. The flexural strength appears to be independent of the width of the specimen. The 1/4-inch-wide specimens of BM-200 and BM-3510 were hard to machine and had burred edges. The burred edges are believed to be the cause of the reduced strength of these specimens.

The most noticeable effect is the lower strength obtained with the thicker specimens of the long-fiber materials, BM-250, BM-200, and BM-3510. It should be noted that this effect would invalidate studies of the effect of span-depth ratio in which different ratios are obtained with specimens of different molded thicknesses. The effect does not appear in the case of the woodflour-filled material, BM-45, and gradually becomes more pronounced for increasingly fibrous materials. This selectivity of the thickness effect indicates that it is caused by the fibrous fillers rather than by curing effects.

Additional studies of the effect of thickness and curing time on flexural strength were made with BM-120, a molding material which showed only a slight difference between thicknesses of 1/8 and 1/4 inch. Specimens were taken from 4-inch disks molded in thicknesses between 1/16 inch and 3/8 inch. Disks were molded for the minimum length of time required to produce sound moldings and for twice that length of time. The results of the flexural strength tests are given in table VI and shown graphically in figure 7. These data show that minimum and double cures make only a slight difference for this material. The effect of thickness becomes more pronounced for 1/16- and 3/32-inch thicknesses, which are more nearly comparable to the lengths of the fibrous filler in this material.

Comparative tensile tests with different types of specimens.- The data for tensile strength which are published in manufacturers' data books have been obtained using the "dogbone" specimen described in Method No. 1012 of Federal Specification L-P-406a and in A.S.T.M. Method of Test D 651-42T. The use of the "dumbbell" specimen described in Method No. 1011 of Federal Specification L-P-406a and A.S.T.M. Method of Test D 638-42T has been considered for replacing the dogbone specimen by A.S.T.M. Committee D-20 on Plastics. The two specimens are shown in figure 4. Reports on comparative test data have been inconsistent.

Comparative tensile test results obtained with molded dumbbell specimens, dumbbell specimens machined from 1/8- and 1/4-inch-thick molded sheets, and results obtained in other laboratories with both specimens are listed in table VII. Data from the manufacturers' bulletins are included for comparison. In general, the dogbone specimens indicate higher strengths with lower coefficients of variation. The test data reported by the Bakelite Corporation for dumbbell specimens are more erratic than those obtained at the National

Bureau of Standards. Almost without exception larger specimens of both shapes show lower coefficients of variation. The significance of the results obtained with the dogbone specimens has been questioned generally because of the shape of the test piece.

The most variable results with dumbbell specimens molded at the National Bureau of Standards were obtained with Resinox 6905, a material containing chopped tire cord. The pieces of tire cord have lengths varying between 1/2 and 3 inches. In the molded dumbbell specimen the lengths of cord have a preferred orientation along the length of the specimen. The strength of a specimen would be high if a number of the longer lengths extended through the reduced section and low if, as a matter of chance, none bridged the distance. The failure of specimens of this material differed from the failures of the other materials in that the specimens were not completely severed. The variety of stress-strain diagrams obtained with Resinox 6905 is shown in figure 8. The dogbone specimen would permit most of the cords to be anchored in the ends of the specimens. The dogbone specimen would, therefore, be expected to give higher results.

None of the other materials contain pieces of filler long enough to bridge the reduced section of the dumbbell specimen, but many of the materials contain fibers sufficiently long to bridge the reduced section of the dogbone specimen. These materials show much lower strengths with the dumbbell specimen. The woodflour-filled material, the fibers of which are too short to bridge the reduced section of either specimen, shows a greater strength with the dumbbell specimen than is reported for the dogbone specimen. It is obvious from this dicussion that an erroneous impression of the tensile strength of a molded part may be obtained from tests of standard specimens.

The results obtained with the machined dumbbell specimens are in good agreement with the results obtained with the molded dumbbell specimens except for the asbestos-filled material BM-250. Since different batches of molding materials were used for preparing the different specimens, perfect agreement cannot be expected. The slightly higher results obtained by the Bell Telephone Laboratory for BM-3510 may have been caused by the higher rate of loading.

<u>Stress-strain relationships</u>.- Typical tensile stress-strain diagrams for molded dumbbell specimens are shown in figure 9. These curves were obtained with stronger-than-

average specimens. The average ultimate strength for each material is indicated on the curves. A stress-strain diagram for cast iron (reference 7, p. 356) is given for comparison. The tensile stress-strain diagrams obtained with eight molded specimens of Resinox 6905 are shown in figure 8.

The stress-strain curves for all the phenolic molding materials are similar to the curve for cast iron and also to curves for concrete in compression and tension (reference 8, pp. 119 and 120). These curves indicate that the molded phenolic plastics behaved like typical brittle materials in the tensile tests.

Typical flexural load-deflection diagrams for six phenolic materials are shown in figure 10. Other reports, for example, reference 9, p. 122, show similar contrasting curves for woodflour- and fabric-filled materials. The flexural test emphasizes the differences between the materials. In the flexural test the failure of a surface fiber in tension will produce a succession of beams of diminishing depth which will offer diminishing resistance to the motion of the loading device. The materials containing short fibers offer little resistance to the progress of the failure through the beam and consequently show brittle failures. The type of failure depends on the degree of orientation of the fibers across the fracture.

Tensile moduli of elasticity.- The tensile moduli of elasticity of the molding materials are given in table VIII. These moduli were obtained with a nonaveraging strain gage and consequently are affected by any initial warping of the specimens. The differences between the results obtained for the short-fiber materials with machined and molded specimens are masked by the variability of the results. The differences observed for BM-250, BM-200, and BM-3510 are large enough to be significant, although they are not consistent.

The tensile modulus of elasticity of the asbestos-filled material, BM-250, as determined with molded dumbbell specimens, varied between 1.64×10^6 psi for a specimen 0.204 inch thick to 2.22×10^6 psi for a specimen 0.121 inch thick. The moduli of intermediate thicknesses fell in regular sequence between these limits. The moduli of the specimens machined from the flat sheets show only a slight change with thickness and are higher than the moduli of the molded specimens. The other materials did not show this effect.

It is thought that this behavior can be explained as follows: The lengths of the asbestos fibers in BM-250 are short in comparison with the length and width of the reduced section of the molded dumbbell specimen, but are comparable to the thickness. In the central portion of the specimen, away from the edges, the fibers are oriented flatwise in the same way as in molded flat sheets. Along the edges the fibers are oriented parallel to the surface of the molded edge. As the thickness of the molded specimen is decreased, the orientation of the fibers approaches the laminar orientation of the flat sheets. The modulus of elasticity correspondingly approaches the modulus obtained for the flat sheets. The magnitude of the change of modulus with thickness for this material is attributed to the large differences between the properties of the asbestos filler and the resin.

The lengths of the fibrous fillers in BM-200 and BM-3510 are short in comparison with the length of the dumbbell specimen but long in comparison with the width and thickness. Because of these relative dimensions the fibers are oriented along the length of the specimen and cause the moduli of the molded specimens to be higher than those of the specimens machined from flat sheets. The fibers in specimens cut from flat sheets are oriented in the plane of the sheet, but have a random orientation along the length of the specimens.

<u>Flexural moduli of elasticity</u>.- Data for modulus of elasticity in flexure are reported in table IX. These moduli agree fairly well with the tensile moduli reported in table VIII. The moduli determined on 1/2- by 1/2- by 5-inch molded bars are affected by the direction of testing with reference to the direction of application of the molding pressure. The orientation of the fibers in molded bars is shown in figure 4. Since the fibers along the edges can be oriented both parallel to molded edge and perpendicular to the direction of the ram motion, these surface fibers are most highly oriented. Higher results are obtained in edgewise tests when the depth of the beam is taken perpendicular to the direction of ram motion when the most highly oriented fibers are located in the tension and compressive faces of the beam. The effect is greater for materials containing long fibers (large bulk factors), as shown in figure 11.

Impact Properties of Phenolic Plastics

Izod impact tests. - The pendulum type of impact test has been found most useful for comparing the shock resistance of electrical insulating materials of generally similar composition and physical characteristics. The test is reported to be unreliable for indicating the relative shock resistance of materials which differ markedly in composition or mechanical properties (reference 10, p. 87).

The Izod impact strength of the six phenolic molding materials are listed in table X in comparison with data taken from the Bakelite Technical Data Book. The discrepancy between the manufacturers' data and that obtained at the National Bureau of Standards for the macerated fabric-filled materials may depend on the capacities of the machines used. The 4-foot-pound pendulum of the machine used at the National Bureau of Standards was barely sufficient to sever the specimens of BM-200 and BM-3510, although the capacity was three to four times the indicated breaking energy. The specimens which were not completely severed were left attached to the clamped portion by a few threads which acted as a hinge permitting the specimen to fold over out of the path of the pendulum. The other results are in good agreement. The impact strengths were consistently higher for specimens notched perpendicular to the ram motion compared with those notched parallel to the ram motion.

The energy expended in tossing the broken halves of the specimens amounted to about two-thirds of the Izod impact strength in the case of the woodflour-filled material, BM-45. The energy required to toss the broken halves of the specimens in all cases was proportional to the specific gravity of the material and amounted to 0.14 foot-pound per inch of notch per unit of specific gravity. Since this amount of energy does not include any breaking energy, Izod impact strengths of 0.20 and 0.27, values frequently reported for cellulose-filled and mineral-filled materials, respectively, indicate little if any impact resistance. These values apply only to results obtained with the 2- to 4-foot-pound machine with standard specimens. Correcting the Izod impact strength for the tossing energy by subtracting a part of the tossing energy proportional to the residual energy of the pendulum after the Izod test, accentuates the differences between materials and between directions of testing. It throws little light on the actual differences between the impact resistance of the materials.

The work involved in breaking an unnotched impact bar in flexure is also reported in table X. The work to maximum load and the total work to break the specimens were determined from the areas of the load-deflection diagrams (fig. 10). The areas were obtained with a planimeter. The work to maximum load does not show any consistent relationship to the Izod impact strength. The total work separates the fabric-filled materials from the other because of the large amount of work done after failure. Hazen (reference 11) reports that static bending tests give mineral-filled phenolic materials toughness ratings more nearly in agreement with ordinary experience, but that the test underrates the toughness of fabric-filled materials such as BM-3510. However, Hazen included only the work done to the maximum load in his ratings. He reported a value of 0.691 foot-pound per cubic inch for BM-3510 as compared with a value of 0.85 for work to maximum load obtained in this laboratory. The total work was about 1.5 foot-pounds per cubic inch, indicating that the energy to tear the fabric-filled materials after failure may account for a large part of the measured impact strength.

Falling-ball impact tests.- The results of progressive-repeated falling-ball impact tests on 4-inch disks of BM-120 are given in table XI. The magnitude of the last impact in a series of impacts which caused failure is proportional to a power of the thickness between one and two. Since a number of other factors, such as the diameter-to-thickness ratio of the disks, the number of impacts, and the velocity of the final impact are variable, the results are considered from a purely empirical viewpoint, assuming proportionality to the square of the thickness. As long as comparisons are made between sheets of the same nominal thickness, the exact relationship need not be known. The relationship between the magnitude of the final impact energy on this basis and the number of impacts is shown in figure 12. This curve shows a trend with thickness similar to that observed for flexural strength shown in figure 7.

On the basis of these results, similar progressive-repeated impact tests were made on rectangular sections cut from molded flat sheets of the six phenolic molding materials. The results of these tests are given in table XII. The series of impacts on the 1/4-inch-thick sheets with a 2-pound ball caused failure at about the same impact energy per unit of thickness squared as that of a larger number of higher velocity impacts with the 1/2-pound ball. The energy required to crack the tension side of the plates appears to be

independent of the filler and consequently shows no correlation with the Izod impact strength. The degree of cracking required to define failure was arbitrarily chosen as the first visible crack. In the case of the fibrous materials the widening of the crack occurred very gradually. The foregoing conclusions could, therefore, be changed appreciably by a different interpretation as to when failure occurred.

The energy required to disrupt the specimens completely shows a very definite increase for increasingly fibrous materials. A comparison with the results of the Izod impact test is shown in figure 13. Since the cracking energy is practically constant for the different materials, it is apparent that high Izod impact strength indicated high tearing strength.

Impact-flexural test.- This test was devised to evaluate the damage to the specimens of the long-fiber materials in the falling-ball test. Since the energy required to crack the specimens in the falling-ball test was practically independent of the filler, the different behavior of the materials must be attributed to their differing ability to sustain partial failure without total loss of strength.

The effect of single impacts on the flexural strengths of simple beams is given in table XIII. Each impact value in the table represents tests on 14 to 21 specimens 1/2 inch wide cut from the 1/8-inch-thick molded flat sheets. Most of these specimens received impacts close to or within the range of impacts which caused cracking. The short-fiber materials BM-45, BM-120, and BM-6260 did not indicate a range of cracking energies but were either completely broken or not apparently damaged by the impact. The flexural strengths, including zeros for specimens broken by the impact alone, were averaged in appropriate ranges of impact energies. The curves for BM-120 and for BM-3510, a long-fiber material, are shown in figure 14. The impact energies, expressed in inch-pound per thickness squared, required to reduce the average flexural strength to 10,000 and 5,000 pounds per square inch, respectively, were determined graphically from curves of the residual flexural strength plotted against the impact energy. Comparison of these impact energies with the Izod impact strengths of these materials is shown in figure 15.

Good correlation is observed for the short-fiber materials (bulk factors less than 4) and long-fiber materials

(bulk factors greater than 4), respectively, but different proportionality factors are involved for the two classes of materials.

Strength Properties of Molded Boxes

The flexural strengths of specimens cut from the molded boxes are compared with data obtained on specimens from the 1/8-inch-thick molded flat sheets in table XIV. The locations of the specimens cut from the boxes are shown in figure 16. The smoother outer surface of the boxes was made the tension side of the beam. The strengths of specimens from the boxes are in good agreement with the strengths of specimens from the 1/8-inch-thick sheets, except for boxes made from BM-250.

The reduced strength of the asbestos-filled material BM-250 may be caused by a number of factors. The boxes of this material were molded from preforms instead of loose powder which was used for boxes of the other materials. BM-250 is the only mineral-filled material represented and has a mold shrinkage less than that contemplated by the mold designer. The significant difference observed for specimens cut at right angles to one another suggests that the direction of flow from the single preform results in a special orientation of filler in this molded box.

The breaking strengths of the boxes molded from the six phenolic materials are given in table XV. A comparison with the flexural strengths of specimens cut from the molded boxes is shown in figure 17. The strength of the boxes does not correlate with any of the tensile or flexural strengths determined in the course of this investigation.

The failure of the boxes made from the short-fiber materials was sudden and complete. The boxes made of the long-fiber materials showed signs of failure at about the same load which caused complete failure of the short-fiber materials but were able to withstand considerably higher loads in spite of numerous cracks. The manner of failure was very similar to the failure of the flat sheets in the falling-ball test.

A comparison of the strengths of the boxes with the results of the falling-ball test on the 1/4-inch-thick sheets is shown in figure 18. Correlation of the strengths of the boxes with the results of the Izod impact test on

standard molded specimens is shown in figure 19, with the isotropic index as determined on molded cylinders in figure 20, and with the bulk factors of the molding powders in figure 21. The last two comparisons show a significant difference between the mineral and cellulose-filled materials. Of the data usually reported in the manufacturers' bulletins the Izod impact strength is the best index of the strength of the boxes. The results are in agreement with the current practice of designing on the basis of impact resistance (reference 12). The strengths of articles of other shapes which would not permit the distribution of the load by partial failure would not be expected to show similar correlation.

Variability of Materials

Coefficients of variation as defined by the formula on page 6 have been reported for most of the test results. The coefficients of variation obtained with small samples are themselves quite variable, as would be expected. The materials containing larger pieces of filler are much more variable than the materials containing woodflour or short cotton flock, particularly in the flexural tests. Thinner moldings of the materials containing fibrous fillers have higher flexural strengths, as stated by the manufacturers, but at the expense of increased variability (table V). Coefficients of variation of larger tensile specimens of both dumbbell and dogbone types are less than coefficients of smaller specimens although the strengths show little change with cross section if the length of the specimen is kept constant (table VII).

In the flexural tests high results were usually accompanied by off-center failures. Low results were obtained when a discontinuity of the filler occurred on the tension face of the beam at midspan. It should be noted, therefore, that both the flexural strengths and the variabilities of the fabric-filled materials determined with the 1/8-inch-thick specimens would have been lower if the strength had been calculated for the stress at the point of failure instead of for failure at midspan.

The largest samples were used for tests of specimens cut from the molded boxes. Coefficients of variation calculated for these results are considered to be typical of the materials. Frequency-flexural strength diagrams for the six phenolic molding materials are shown in figure 22.

The difference in the flexural strength of BM-200 when tested at span-depth ratios of 16:1 and 8:1, respectively, is 700 psi or about 6 percent (table IV). The coefficient of variation considered to be typical of this material in 1/8-inch thickness is 16 percent (table V and fig. 22). In order to establish the significance of the difference in flexural strength it would be necessary to make 130 tests at each span-depth ratio. The use of the five specimens usually required for routine tests of plastic materials is definitely inadequate for determining small differences for such variable materials. For example, five specimens of the above-mentioned material would be sufficient only to establish the significance of a difference of about 30 percent or more.

The nonuniformity of a material, which is indicated by the coefficient of variation, affects the results of tests made with specimens of different sizes and tests with different methods of loading. Tucker (reference 13) presents a treatment of the statistical theory of the effects of dimensions and methods of loading upon strength properties, wherein the "weakest-link" theory developed independently by Weibull (reference 14), and the "strength-summation" theory are discussed in relation to the strength of concrete beams. The statistical analyses as verified by tests on concrete beams indicate that the modulus of rupture (flexural strength) is independent of the width of the beam, but is decreased by an increase in thickness or length. The first two of these conclusions are substantiated by the results reported here of tests on specimens of different widths and thickness cut from the molded flat sheets. The most variable materials show the greatest differences with thickness. The conclusion regarding the effect of length was not checked because it was not possible to isolate the independent effect of span-depth ratio.

The "weakest-link-in-series" theory proposed by Weibull indicates that smaller tensile specimens (shorter lengths) should have higher strengths. This may partially explain the higher results obtained with the dogbone specimens although the effect of orientation of the fillers and the effect of the shape of the specimen may be the principal cause of the difference.

The strength-summation or "links-in-parallel" theory indicates that the tensile strength should be independent of the cross section and that the coefficient of variation should decrease with an increase in cross section. This is

substantially what was observed for the tensile strengths of specimens machined from the 1/8-inch- and 1/4-inch-thick molded flat sheets.

In the foregoing discussion the statistical theory has been applied only qualitatively since the coefficients of variation based on small samples are themselves quite variable. The qualitative agreement with the statistical theory indicates that further work along this line would be useful.

CONCLUSIONS

Conclusions relating particularly to test specimens and methods of test have been presented in the discussion. These findings indicate that the interpretation of the results of tests must take into consideration the characteristics of the individual filler in relation to the particular test piece.

General conclusions are as follows:

1. Phenolic molding materials are generally nonisotropic. The degree of anisotropy depends on the size and shape of the fillers and the dimensions and shape of the molded section.

2. The nonhomogeneity of these materials is reflected in the coefficient of variation which increases with the size of the pieces of filler and is an important characteristic of each material.

3. The flexural strengths of specimens cut from molded boxes were found to be in good agreement with the flexural strengths of specimens from molded flat sheets of approximately equal thickness. An asbestos-filled material BM-250 appears to be an exception to this statement. The reason for the exception has not been established.

4. Tensile and flexural stress-strain curves indicate that phenolic materials are essentially brittle. Fibrous materials, however, are capable of relieving localized stress and distributing the load by partial failure.

5. The breaking strengths of molded boxes correlates well with the results of the falling-ball impact test on flat sheets molded of the same materials. Good correlation

is also obtained with the Izod impact strength as determined on standard test specimens. Good correlation with the bulk factor of the powder also was observed.

6. The trends observed in this investigation for the behavior of standard test specimens agree qualitatively with conclusions derived from statistical analysis of the effects of dimensions and methods of loading upon the strength properties of concrete beams. It is concluded that further work along these lines is desirable.

National Bureau of Standards,
Washington, D. C., July 25, 1945.

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TABLE I.– DESCRIPTION OF PHENOLIC MOLDING MATERIALS

Manufacturers' designation	Filler	Mean bulk factor[1] (Manufacturers' data)
Bakelite BM–45	Woodflour	2.45
Bakelite BM–120	Woodflour and cotton flock	2.58
Bakelite BM–6260	Woodflour and cotton flock	3.8
Bakelite BM–250	Long–fiber asbestos	8.0
Bakelite BM–200	Macerated fabric	9.5
Bakelite BM–3510	Macerated fabric	14.5
Resinox 7013	Mica	2.64
Resinox 6565	Long cotton flock	5.5
Resinox 6905	Tire cord	6.5
Resinox 6542	Macerated fabric	10.0

[1]Bulk factor – The ratio of the volume of the molding composition to the volume of the finished molding.

TABLE II.- MOLDING CONDITIONS USED IN PREPARATION OF TEST PIECES

Material	Batch No.	Mean Bulk Factor[a]	Molder	Type of Molding or Specimen	Thickness (in.)	Molding Conditions[b] Temp. (°F)	Pressure (lb/in²)	Time (min)	Cooling Time (min.)
BM-45	178	2.45	NBS	Dumbbell	0.16-0.25	300	2,000	48	none
			NBS	Flexure Bar	0.14-0.20	300	2,000	48	none
			NBS	do.	0.17-0.19	320	3,000	3-1/2	none
			NBS	2" Cylinder	1.30	300	2,000	48	none
			NBS	do.	0.97	300	6,000	15[c]	none
	182A		Bak.Corp.	Flat Sheets	1/8 and 1/4	320	1,700	15	5
			G.E. Co.	Boxes	1/8	320	d	7	3
			NBS	Impact Bar	1/2	310	5,600	8	none
BM-120	638	2.58	NBS	Dumbbell	0.14-0.25	300	2,500	24	none
			NBS	Flexure Bar	0.14-0.19	300	2,500	24	none
			NBS	2" Cylinder	1.18	300	2,500	24	none
	670		NBS	4" Disk	1/8	310	3,000	1-1/2[e]	none
			NBS	do.	1/8	310	3,000	3[e]	none
			NBS	do.	1/4	310	3,000	2-1/2[e]	none
			NBS	do.	1/4	310	3,000	5[e]	none
			NBS	do.	3/8	310	3,000	4[e]	none
			NBS	do.	3/8	310	3,000	8[e]	none
	744C		Bak. Corp.	Flat Sheets	1/8 and 1/4	320	1,700	15	5
			G.E. Co.	Boxes	1/8	320	d	7	3
			NBS	Impact Bar	1/2	310	5,600	8	none
			NBS	4" Disk	1/16,3/32 & 1/8	310	3,000	2[f]	none
			NBS	do.	1/16,3/32 & 1/8	310	3,000	4[f]	none
R-7013	Unknown	2.64	NBS	Dumbbell	0.15-0.26	300	4,000	20[g]	none
			NBS	Flexure Bar	0.16-0.20	300	4,000	20[g]	none
			NBS	2" Cylinder	1.12	75-300	2,000	60[h]	none
BM-6260	Unknown	3.8	NBS	Dumbbell	0.14-0.25	300	2,000	15	none
	1221		NBS	Flexure Bar	0.15-0.18	300	2,000	15	none
	Unknown		NBS	2" Cylinder	1.13	300	2,000	15	none
	1221		NBS	do.	1.39	300	(6,000	(5[c]	none
							(2,000	(15	none
	1221		Bak.Corp.	Flat Sheets	1/8 and 1/4	320	1,700	15	5
	1221 & 1359		G.E. Co.	Boxes	1/8	320	d	7	3
	1221		NBS	Impact Bar	1/2	310	5,600	8	none
R-6565	6519	5.5	NBS	Dumbbell	0.18-0.34	300	4,000	15	none
			NBS	Flexure Bar	0.15-0.20	300	4,000	15	none
			NBS	2" Cylinder	1.63	300	(6,000	5	none
							(2,000	15	none
R-6905	476	6.5	NBS	Dumbbell	0.12-0.32	300	4,000	15	none
			NBS	Flexure Bar	0.15-0.25	300	4,000	15	none
			NBS	2" Cylinder	1.09	300	(6,000	(5	none
							(2,000	(15	none
BM-250	168C	8.0	NBS	Dumbbell	0.12-0.20	300	3,000	46	none
			NBS	Flexure Bar	0.12-0.14	300	3,000	46	none
			NBS	2" Cylinder	1.01	75-300	2,000	60 h	none
	191B		NBS	Impact Bar	1/2	290	5,600	16	none
	202D		Bak.Corp.	Flat Sheets	1/8 and 1/4	320	1,700[i]	15	5
			G.E. Co.	Boxes	1/8	320	d & j	7	3
	207H		G.E. Co.	Boxes	1/8	320	d & k	5	none
BM-200	67A Black	9.5	NBS	Dumbbell	0.13-0.28	300	5,000	15	none
			NBS	Flexure Bar	0.15-0.18	300	5,000	15	none
			NBS	2" Cylinder	1.07	300	(10,000	5	none
							(2,000	15	none
	27 Brown		Bak.Corp.	Flat Sheets	1/8 and 1/4	320	1,700	15	5
	23 & 27 Brown		G.E. Co.	Boxes	1/8	320	d	7	3
	72 Black		NBS	Impact Bars	1/2	310	5,600	8	none
R-6542	6740	10.0	NBS	Dumbbell	0.14-0.24	300	4,000	15	none
			NBS	Flexure Bar	0.14-0.19	300	4,000	15	none
			NBS	2" Cylinder	1.10	300	(8,000	10	none
							(2,000	32	none
BM-3510	1660F	14.5	NBS	Dumbbell	0.12-0.22	300	4,000	15	none
			NBS	Flexure Bar	0.14-0.16	300	2,250	15	none
			NBS	2" Cylinder	1.10	300	(10,000	(10	none
							(2,000	(26	none
	1985		Bak.Corp.	Flat Sheets	1/8 and 1/4	320	1,700	15	5
	1985 & 2112		G.E. Co.	Boxes	1/8	320	d	7	3
	1318D		NBS	Impact Bars	1/2	310	5,600	8	none

a. Data from Manufacturers' bulletins.
b. Preforms prepared at room temperature were used for all moldings at the National Bureau of Standards unless otherwise indicated. Moldings were not breathed except as indicated.
c. Preforms prepared at 150°F, 6,000 lb/in².
d. Pressure of 1,100 lb/in² reported by General Electric Co. Since the mold is not fully positive, pressure on plastic is indefinite. Materials preheated in an oven at 176° F for 10 minutes. Molded without preforms.
e. Powder preheated in oven for 15 minutes at 175°F, and preformed at 175°F, 3,000 lb/in². Mold was closed in 15 seconds and breathed 10, 20, 30 and 40 seconds after closing.
f. No preforms used. Mold was closed in 15 seconds and breathed 10 and 20 seconds after closing.
g. Preformed at approximately 200°F, 18 tons force.
h. Powder placed in cold mold and heated to 300°F in 30 minutes
i. Mold breathed 3 times at 3 to 5 second intervals, starting 15 seconds after mold was closed.
j. Preform 5 by 5-1/4 by 5/8 inch prepared at approximately 4.5 tons/in².
k. Material preheated at 210°F, for 10 minutes cooled to room temperature and preformed.

TABLE III.- ISOTROPY OF MOLDED PHENOLIC CYLINDERS

Material	Mean Bulk Factor	Length of Cylinder[a] (in.)	Flexural Strength Parallel to Ram Motion: Average (lb/in^2)	Flexural Strength Parallel to Ram Motion: Range (lb/in^2)	Flexural Strength Parallel to Ram Motion: Span-depth Ratio[b]	Flexural Strength Parallel to Ram Motion: No. of Tests	Flexural Strength Perpendicular to Ram Motion: Average (lb/in^2)	Flexural Strength Perpendicular to Ram Motion: Range (lb/in^2)	Flexural Strength Perpendicular to Ram Motion: Span-depth Ratio[b]	Flexural Strength Perpendicular to Ram Motion: No. of Tests	Isotropic Index[c]
BM-45	2.45	1.30 0.97	7,900 7,300	7,500-8,300 6,300-7,900	6.5 8.0[d]	6 9	9,000 8,900	8,200-9,900 7,600-9,900	6.4 8.0[d]	5 5	0.88 0.82
BM-120	2.58	1.18	8,700	7,600-9,800	7.5	10	10,400	9,600-11,200	6.7	10	0.85
R-7013	2.64	1.12	3,600	3,100-4,400	6.5	5	5,800	4,300-7,200	7.1	6	0.61
BM-6260	3.8	1.13 1.39	7,200 7,300	5,700-8,800 6,300-7,800	7.1 8.0[d]	6 8	9,200 9,800	7,500-10,800 9,000-10,200	6.9 8.0[d]	6 7	0.79 0.75
R-6565	5.5	1.63	4,400	3,600-5,800	6.6	8	8,900	7,500-10,900	6.4	6	0.50
R-6905	6.5	1.09	3,700	2,600-5,600	4.5	6	8,200	7,000-10,300	4.5	5	0.45
BM-250	8.0	1.01	3,700	3,100-4,100	6.5	6	10,100	7,900-11,100	7.0	5	0.37
BM-200	9.5	1.07	4,500	3,400-5,600	7.7	6	11,500	10,000-13,700	7.4	5	0.40
R-6542	10.0	1.10	5,000	3,800-6,600	6.3	6	11,800	8,500-13,400	6.2	5	0.43
BM-3510	14.5	1.10	4,800	3,100-6,200	7.2	5	12,400	9,800-14,800	7.7	5	0.39

a. Cylinders were 2 inches in diameter.
b. Average ratio for group of nearly uniform specimens; pressure piece and supports had 1/8-inch radii.
c. The isotropic index is defined as the ratio of flexural strengths of specimens cut with their long axes parallel and perpendicular, respectively, to the direction of the ram motion.
d. Span adjusted to obtain uniform span-depth ratio; pressure piece and supports had 1/32 inch radii.

TABLE IV.- VARIATION OF FLEXURAL STRENGTH WITH SPAN-DEPTH RATIO FOR MOLDED PHENOLIC PLASTICS SPECIMENS 1 INCH WIDE

Material	Average Thickness (in.)	Average Span-Depth Ratio	Flexural Strength				Average Span-Depth Ratio	Flexural Strength				Average Span-Depth Ratio	Flexural Strength[c]			
			No. of Tests	Average (lb/in²)	S.E.[a] (lb/in²)	V[b] (%)		No. of Tests	Average (lb/in²)	S.E.[a] (lb/in²)	V[b] (%)		No. of Tests	Average (lb/in²)	S.E.[a] (lb/in²)	V[b] (%)
BM-45 (long cure) (short cure)	0.170 0.179	16.9 16.8	6 2	10,300 10,800	±270	6.3	10.5 11.2	6 2	10,500 10,300	±280	6.4	6.8 5.6	6 2	11,700 12,100	±340	7.0
BM-120	0.172	17.1	6	10,300	±410	9.6	11.0	5	10,700	±500	10.4	6.2	11	12,100	±170	4.8
BM-200	0.164	18.4	5	11,500	±420	8.2	12.3	5	12,500	±450	8.0	6.2	5	13,300	±820	13.8
BM-250	0.147 0.128	16.9 23.4	9 3	11,400 11,700	±300	7.9	12.1	3	11,500			6.2	3	11,800		
BM-3510	0.150	20.1	5	11,700	±750	14.3	13.4	5	12,900	±680	11.8	6.7	5	13,600	±550	9.1
BM-6260	0.188	18.7	6	9,900	±250	6.2	10.1	6	10,800	±270	6.1	6.2	6	11,100	±380	8.4
R-6542	0.175	17.4	5	11,700	±540	10.3	11.6	4	12,600			5.8	5	13,700	±950	15.5
R-6565	0.174	18.6	6	9,500	±350	9.0	10.5	6	10,400	±480	11.2	7.0	6	11,800	±580	12.0
R-6905	0.172	18.1	5	11,200	±710	14.1	11.4	5	12,900	±740	12.7	6.6	5	13,800	±1,240	20.0
R-7013	0.182	16.5	5	6,900	±350	11.3	11.0	5	6,900	±360	11.6	5.6	4	7,200	±250	7.0

a. S.E. = standard error of the mean.
b. V = coefficient of variation.
c. Specimens 1/2 inch wide.

TABLE V.- EFFECT OF DIMENSIONS OF SPECIMENS ON FLEXURAL STRENGTH

Material	Batch No.	Type of Specimen[a]	Tests at Span-depth Ratio of 16:1[b]						Tests at Span-depth Ratio of 12:1[c]						Tests at Span-depth Ratio of 8:1[c]					
			Dimensions of Specimens		Flexural Strength				Dimensions of Specimens		Flexural Strength				Dimensions of Specimens		Flexural Strength			
			Width, Average (in.)	Thickness, Average (in.)	No. of Tests	Average (lb/in²)	S.E.[d] (lb/in²)	V[e] (%)	Width, Average (in.)	Thickness, Average (in.)	No. of Tests	Average (lb/in²)	S.E.[d] (lb/in²)	V[e] (%)	Width, Average (in.)	Thickness, Average (in.)	No. of Tests	Average (lb/in²)	S.E.[d] (lb/in²)	V[e] (%)
BM-45	178	B	1.00	0.170	6	10,300[f]	±270	6.3												
	Unknown	B													1/2	1/2		8,800[g]		
	178	B,F													0.50	0.48	2	10,400	(Range 10,200-10,500)	
	178	B,E													0.48	0.50	2	11,000	(Range 10,600-11,400)	
	182a	S	0.25	0.137	5	11,400	±420	8.3	0.25	0.135	5	11,800	±710	13.4	0.25	0.140	5	12,100	±640	11.7
	182a	S	0.25	0.265	6	11,500	±480	10.2												
	182a	S	0.50	0.140	6	11,200	±610	13.4	0.50	0.136	6	11,300	±440	9.6	0.50	0.144	6	11,900	±690	14.1
	182a	S	0.50	0.265	6	11,700	±340	7.1												
	182a	S	0.92	0.139	6	11,400	±510	10.9	0.92	0.139	6	11,100	±560	12.4	0.92	0.139	6	11,800	±660	13.7
	182a	S	0.93	0.264	6	11,900	±240	5.0												
BM-120	638	B	1.00	0.172	6	10,400[f]	±370	8.7												
	Unknown	B													1/2	1/2		10,000[g]		
	638	B,F													0.50	0.48	2	11,000	(Range 10,500-11,500)	
	638	B,E													0.48	0.50	2	12,000	(Range 11,600-12,400)	
	744C	S	0.25	0.151	3	13,700	(Range 13,000-14,300)		0.25	0.310	6	12,900[b]	±320	6.2						
	744C	S	0.50	0.155	6	13,800	±440	7.9	0.50	0.309	6	12,700[b]	±260	4.9	0.50	0.162	10	14,100	±450	10.1
	744C	S	0.96	0.150	6	13,900	±710	12.5	0.96	0.307	6	12,900[b]	±200	3.9						
BM-6260	Unknown	B	1.00	0.188	6	10,200[f]	±230	5.6												
	Unknown	B													1/2	1/2		10,000[g]		
		B,F													0.50	0.49	2	9,200	(Range 9,200-9,300)	
		B,E													0.49	0.50	2	10,600	(Range 10,500-10,800)	
	1221	S	0.25	0.138	6	11,800	±380	7.8	0.25	0.138	6	10,800	±150	3.3	0.25	0.138	6	11,200	±380	8.2
		S	0.25	0.268	6	10,000	±340	8.3												
		S	0.50	0.138	6	11,200	±360	7.9	0.50	0.134	6	10,600	±330	7.6	0.50	0.142	6	11,300	±530	11.4
		S	0.50	0.268	6	9,600	±250	6.4												
		S	0.93	0.138	6	10,400	±480	11.3	0.93	0.138	6	10,400	±300	7.0	0.93	0.137	6	11,200	±390	8.6
		S	0.93	0.268	6	9,800	±300	7.5												
BM-250	168C	B	1.00	0.147	6	11,400[f]	±100	1.9												
	Unknown	B													1/2	1/2		10,000[g]		
	168C	B,F													0.50	0.48	2	11,200	(Range 11,000-11,300)	
		B,E													0.48	0.50	2	11,800	(Range 11,200-12,500)	
	202D	S	0.25	0.136	5	12,800	±240	4.1	0.25	0.137	5	12,700	±890	15.6	0.25	0.136	6	12,000	±880	18.1
		S	0.25	0.266	6	10,300	±670	16.0												
		S	0.50	0.135	6	12,800	±890	17.1	0.50	0.134	6	12,700	±980	18.9	0.50	0.136	6	12,800	±680	13.0
		S	0.50	0.267	6	11,000	±260	5.8												
		S	0.91	0.134	6	12,500	±640	13.5	0.91	0.133	6	12,500	±700	13.7	0.91	0.136	6	12,800	±580	11.0
		S	0.92	0.267	6	11,400	±300	6.5												
BM-200	67a Black	B	1.00	0.164	5	12,000[f]	±330	6.2												
	Unknown	B													1/2	1/2		9,500[g]		
	67a Black	B,F													0.50	0.49	2	10,900	(Range 9,900-12,000)	
		B,E													0.48	0.50	2	11,600	(Range 11,600-11,700)	
	27 Brown	S	0.24	0.145	6	10,700[h]	±770	17.6	0.25	0.144	6	10,600[h]	±910	21.0	0.25	0.146	6	11,000[h]	±720	16.0
		S	0.25	0.255	6	8,600[h]	±400	11.3												
		S	0.50	0.144	6	13,300	±1,100	20.7	0.50	0.143	6	11,700	±340	7.1	0.50	0.145	6	12,100	±420	8.4
		S	0.50	0.254	6	10,000	±680	16.7												
		S	1.01	0.143	6	13,100	±850	16.0	1.02	0.143	6	11,800	±930	19.4	1.02	0.144	6	12,100	±1,200	24.3
		S	1.02	0.252	6	10,200	±160	4.0												
BM-3510	1660F	B	1.00	0.150	5	12,600[f]	±790	14.0												
	Unknown	B													1/2	1/2		9,000[g]		
	1660F	B,F													0.50	0.50	2	11,600		
		B,E													0.49	0.50	2	12,000	(Range 11,500-12,500)	
		S	0.25	0.135	6	12,600[h]	±600	11.7	0.25	0.135	6	11,400[h]	±780	16.8	0.25	0.135	6	9,800[h]	±330	8.4
		S	0.25	0.266	6	10,000[h]	±460	11.2												
		S	0.50	0.135	6	12,000	±840	17.1	0.50	0.136	6	10,800	±650	14.8	0.50	0.134	6	12,700	±900	17.4
		S	0.50	0.265	6	10,600	±510	11.9												
		S	0.99	0.134	6	12,300	±420	8.3	0.99	0.135	6	12,500	±1,000	20.1	0.99	0.134	6	11,200	±770	16.8
		S	0.98	0.264	6	11,000	±580	13.0												

a. B = molded bar; S = machined from flat sheet; F = flatwise (depth in direction of molding ram motion); E = edgewise (depth perpendicular to molding ram motion).
b. Tested with 1/8 inch radii support and pressure pieces.
c. Tested with 1/32 inch radii suppat and pressure pieces.
d. Standard error.
e. Coefficient of variation.
f. Interpolated values from tests at approximate span-depth ratios.
g. Data from manufacturer's Technical Data Book.
h. Specimens had burred edges.

TABLE VI.- EFFECT OF THICKNESS AND CURING TIME ON STRENGTH OF 4-INCH-DIAMETER DISK MOLDINGS OF BAKELITE BM-120 PHENOLIC MOLDING COMPOUND.

Nominal Thickness of Moldings (in.)	Batch No.	Curing Time[a] (min.)	Flexural Strength[b]				
			No. of Tests	Average (lb/in²)	Range (lb/in²)	S.E.[c] (lb/in²)	V[d] (%)
Minimum Cure							
1/16	744C	2	20	12,300	10,500-13,700	±180	6.6
3/32	744C	2	16	11,900	10,600-13,300	±170	5.8
1/8	744C	2	7	11,200	10,000-12,300	±270	6.3
1/8	670	1-1/2	10	10,900	9,300-12,300	±330	9.6
1/4	670	2-1/2	10	12,200	11,200-13,200	±170	4.4
3/8	670	4	8	11,100	9,900-12,500	±300	7.7
100% Overcure							
1/16	744C	4	20	13,200	12,000-15,700	±220	7.5
3/32	744C	4	16	12,700	11,500-14,100	±170	5.5
1/8	744C	4	7	12,200	11,200-13,300	±270	5.8
1/8	670	3	10	11,800	11,100-12,500	±150	4.1
1/4	670	5	10	11,300	9,100-12,400	±380	10.6
3/8	670	8	6	11,000	9,000-11,900	±400	9.6

a. Molded at 310° F and 3,000 lb/in²
b. Tested at a span-depth ratio of 8:1.
c. Standard error
d. Coefficient of variation.

TABLE VII.- TENSILE STRENGTH OF MOLDED PHENOLIC MATERIALS DETERMINED WITH DIFFERENT TYPES OF SPECIMENS
(Rate of Head Motion for NBS Tests with Dumbbell Specimens was 0.05 in/min.)

Material	Molded Dumbbell Specimens					Molded Dogbone Specimens					Machined Dumbbell Specimens				
	Average Thickness (in.)	No. of Specimens	Tensile Strength Average (lb/in²)	Tensile Strength S.E.[a] (lb/in²)	V[b] (%)	No. of Specimens	Reduced Section Thickness (in.)	Tensile Strength Average (lb/in²)	Tensile Strength S.E.[a] (lb/in²)	V[b] (%)	No. of Specimens	Average Thickness (in.)	Tensile Strength Average (lb/in²)	Tensile Strength S.E.[a] (lb/in²)	V[b] (%)
BM-45	0.181	5	6,950	±160	5.2			6,000[c]			6	0.133	7,850	±280	8.5
											6	0.261	7,240	± 60	2.0
BM-120								8,500[c]							
	0.167	7	6,510	±200	8.2	6	1/8	8,460[d]	±170	4.9	6	0.146	8,130	±140	4.2
	1/8	12	6,990[d]	±240	11.6	6	1/4	8,420[d]	±150	4.3	6	0.302	7,910	±130	4.0
	1/4	12	6,610[d]	±180	9.6										
	1/8	20	5,650[d]	±190	14.8										
	1/4	20	7,070[d]	±190	12.0										
R-7013	0.212	5	3,240	±140	9.9			6,500[c]							
BM-6260	0.154	9	6,750	±150	6.7			8,500[c]			6	0.135	6,530	±220	8.3
	1/8	12	6,620[d]	±300	15.9	6	1/8	8,160[d]	±220	6.6	6	0.264	6,910	±140	5.1
	1/4	12	7,340[d]	±200	9.3	6	1/4	7,800[d]	±170	5.5					
R-6565	0.224	8	5,250	± 70	3.9			7,500[c]							
R-6905	0.193	8	4,260	±160	10.5			6,500[c]							
BM-250	0.149	7	4,840	±130	8.4			6,000[c]			6	0.133	6,900	±250	9.0
	0.149	3	3,000[e]	±700	41.						6	0.267	6,870	±190	6.9
BM-200	0.180	8	5,830	±110	5.4			6,700[c]			6	0.143	4,950	± 70	3.3
											6	0.250	5,730	±200	9.0
R-6542	0.180	7	5,800	±140	6.2			7,500[c]							
BM-3510	0.182	8	5,910	±170	8.1			6,500[c]			6	0.134	5,410	±230	10.5
											6	0.263	5,710	±150	6.4
											7	1/8	6,070[f]	±160	6.8

a. S.E. = standard error of the mean.
b. V = coefficient of variation.
c. Data from manufacturer's Bulletins.
d. Test data received from Bakelite Corp.
e. Specimens were molded without the use of preforms; all other NBS specimens were molded from preforms.
f. Test data from Bell Telephone Laboratories; rate of head travel 0.10 inch per minute.

TABLE VIII.- TENSILE MODULI OF ELASTICITY OF MOLDED PHENOLIC MATERIALS
(Specimens were the dumbbell type specified in Method 1011, Federal Specifications L-P-406a)

Material	Specimens			Tensile Secant Modulus, 0-2500 lb/in²				
	Type	Thickness						
		Average (in.)	Range (in.)	No. of Tests	Average (10^6 lb/in²)	Range (10^6 lb/in²)	S.E.[a] (10^6 lb/in²)	V[b] (%)
BM-45	Molded	0.192	0.160-0.248	6	1.15	1.08-1.27	±.03	5.8
	Machined	0.137	0.132-0.139	4	1.13	1.05-1.22	±.04	6.7
	do.	0.264	0.258-0.267	5	1.07	1.03-1.11	±.02	3.1
BM-120	Molded	0.172	0.143-0.253	8	1.15	1.08-1.23	±.02	5.0
	Machined	0.155	0.146-0.160	6	1.10	1.03-1.16	±.02	5.1
	do.	0.305	0.303-0.307	5	1.08	1.04-1.11	±.01	2.9
BM-200	Molded	0.180	0.127-0.282	8	1.31	1.23-1.39	±.02	4.3
	Machined	0.144	0.140-0.147	5	1.11	1.04-1.15	±.02	4.0
	do.	0.252	0.250-0.255	6	1.16	1.11-1.22	±.02	3.7
BM-250	Molded	0.156	0.121-0.206	6	1.92	1.64-2.22	±.08	10.5
	Machined	0.134	0.131-0.138	4	2.47	2.22-2.70	±.11	9.2
	do.	0.269	0.262-0.275	5	2.29	2.08-2.44	±.07	6.7
BM-3510	Molded	0.182	0.122-0.226	8	1.27	1.19-1.33	±.02	4.5
	Machined	0.136	0.131-0.142	6	1.03	0.93-1.15	±.03	8.0
	do.	0.266	0.257-0.280	6	1.05	1.00-1.09	±.01	3.2
BM-6260	Molded	0.169	0.127-0.247	8	0.95	0.83-1.05	±.03	7.7
	Machined	0.138	0.125-0.146	6	0.97	0.90-1.06	±.03	6.6
	do.	0.268	0.257-0.273	6	0.95	0.92-0.98	±.01	2.7
R-6542	Molded	0.155	0.143-0.235	7	1.17	1.03-1.37	±.04	9.2
R-6565	Molded	0.224	0.183-0.342	8	0.88	0.81-0.96	±.02	5.2
R-6905	Molded	0.193	0.124-0.320	8	1.14	0.93-1.27	±.05	11.5
R-7013	Molded	0.200	0.154-0.257	4	2.46	2.27-2.63	±.07	6.1

a. S.E. = standard error
b. V = coefficient of variation.

TABLE IX.- FLEXURAL MODULI OF ELASTICITY OF MOLDED PHENOLIC MATERIALS

Material	Type of Specimen	Direction of Testing[a]	Depth, Average (in.)	Width, Average (in.)	Span-depth Ratio	No. of Tests	Initial Flexural Modulus of Elasticity		Moduli of Elasticity[b] Reported by Manufacturer (10^6 lb/in^2)
							Average (10^6 lb/in^2)	Range (10^6 lb/in^2)	
BM-45	Molded Bar	Flatwise	0.475	0.499	8	2	0.94	0.939-0.948	0.89
	Molded Bar	Edgewise	0.499	0.478	8	2	1.00	1.00 -1.01	
	1/8-inch flat sheet	Flatwise	0.139	0.92	16	6	1.04	0.98 -1.07	
	1/8-inch flat sheet	Flatwise	0.140	0.50	16	6	1.01	0.87 -1.08	
	1/4-inch flat sheet	Flatwise	0.264	0.93	16	6	1.02	1.00 -1.04	
	1/4-inch flat sheet	Flatwise	0.265	0.50	16	6	1.00	0.96 -1.04	
BM-120	Molded Bar	Flatwise	0.476	0.499	8	2	0.93	0.929-0.937	1.0
	Molded Bar	Edgewise	0.499	0.478	8	2	0.93	0.926-0.942	
BM-200	Molded Bar	Flatwise	0.487	0.501	8	2	1.10	1.09 -1.11	1.00
	Molded Bar	Edgewise	0.501	0.485	8	2	1.22	1.20 -1.24	
BM-250	Molded Bar	Flatwise	0.478	0.502	8	2	2.11	2.11 -2.11	1.0[c]
	Molded Bar	Edgewise	0.502	0.476	8	2	2.36	2.35 -2.37	
BM-3510	Molded Bar	Flatwise	0.502	0.502	8	2	1.10	1.08 -1.13	1.
	Molded Bar	Edgewise	0.502	0.491	8	2	1.25	1.22 -1.27	
BM-6260	Molded Bar	Flatwise	0.490	0.501	8	2	0.88	0.857-0.904	1.00
	Molded Bar	Edgewise	0.500	0.488	8	2	0.91	0.908-0.910	

a. Flatwise = depth of beam in direction of ram motion.
   Edgewise = depth of beam perpendicular to ram motion.

b. Data from Bakelite Technical Data Book.

c. Data sheet published January 30, 1942.

TABLE X.- IZOD IMPACT STRENGTH OF MOLDED PHENOLIC MATERIALS

Material[a]	Source of Data	Location of Notch	Capacity of Pendulum (ft-lb)	Izod Impact Strength[b] Average (ft-lb/in. of notch)	Izod Impact Strength[b] S.E.[f] (ft-lb/in. of notch)	Specific Gravity of Specimen	Tossing energy[c] Average (ft-lb/in. of notch)	Tossing Energy Divided by Specific Gravity	Impact Strength[d] corrected for Tossing Energy (ft-lb/in. of notch)	Work to rupture in bending[e] Work to Maximum load (ft-lb/in³)	Work to rupture in bending[e] Total work (ft-lb/in³)
BM-45	NBS	Side[g]	2	0.274	±.007	1.34	0.201	0.150	0.08	0.55	0.55
	NBS	Face[h]	2	0.344	±.010	1.34	0.196	0.146	0.16		
	Bak.Corp.[i]	Side	Unknown	0.26		1.35					
BM-120	NBS	Side	2	0.304	±.006	1.35	0.203	0.150	0.11	0.68	0.68
	NBS	Face	2	0.381	±.010	1.35	0.191	0.141	0.19		
	Bak.Corp.[i]	Side	Unknown	0.32		1.35					
BM-6260	NBS	Side	2	0.339	±.005	1.33	0.208	0.156	0.14	0.53	0.53
	NBS	Face	2	0.369	±.005	1.33	0.199	0.150	0.18		
	Bak.Corp.[i]	Side	Unknown	0.46		1.37					
BM-250	NBS	Side	2	0.90	±.02	1.91	0.257	0.135	0.68	0.43	0.65
	NBS	Face	2	1.06	±.03	1.91	0.241	0.126	0.88		
	Bak.Corp.[i]	Side	Unknown	1.0		1.89					
			Average tossing energy/specific gravity for 2 ft-lb pendulum - - - 0.144								
BM-200	NBS	Side	4	2.34	±.09	1.39	0.207	0.150	j	0.72	1.57
	NBS	Face	4	2.79	±.11	1.39	0.201	0.146	j		
	Bak.Corp.[i]	Side	Unknown	4.6[k]		1.37					
BM-3510	NBS	Side	4	2.41	±.08	1.38	0.209	0.152	j	0.85	1.53
	NBS	Face	4	2.78	±.16	1.38	0.194	0.141	j		
	Bak.Corp.[i]	Side	Unknown	3.8[k]		1.38					
			Average tossing energy/specific gravity for 4 ft-lb pendulum - - - 0.147								

a. Materials are listed in order of increasing bulk factors.
b. Averages are for tests on 9 specimens.
c. The energy to toss the severed ends was determined by fitting the specimen back together and repeating the test.
d. The tossing energy was multiplied by the ratio of the residual energy after breaking to the capacity of the pendulum. This product was subtracted from the impact energy.
e. Work to rupture unnotched impact bar at span-depth ratio of 8:1. Reported values are averages for two tests flatwise and two edgewise. The work per cubic inch was computed from the area of the load-deflection diagrams and the volume of material between the supports.
f. S.E. = standard error.
g. Side is the surface parallel to direction of ram motion.
h. Face is the surface perpendicular to direction of ram motion.
i. Data from Bakelite Technical Data Book.
j. Corrected energy was not computed because specimens were not cleanly severed.
k. Midpoint of range of reported values.

TABLE XI.- PROGRESSIVE-REPEATED FALLING-BALL IMPACT TEST ON 4-INCH-DIAMETER DISKS OF BM-120.

Test No.	Thickness (in.)	Height of Fall[a] (in.)	Energy to Break Specimen[b]		
			(in.-lb)	(in.-lb/in.)	(in.-lb/in^2)
1	0.123	7	3.48	28.3	230
2	0.123	7[c]	3.48	28.3	230
3	0.124	7[c]	3.48	28.0	226
4	0.126	6[d]	2.98	23.7	188
5	0.170	11	5.47	32.2	189
6	0.251	18	8.95	35.6	142
7	0.253	19	9.44	37.4	148
8	0.253	19	9.44	37.4	148
9	0.253	16	7.96	31.4	124
10	0.253	19	9.44	37.4	148
11	0.379	35	17.4	46.0	121
12	0.379	33	16.4	43.3	114
13	0.380	40	19.9	52.4	138

a. Also indicates number of impacts, since height of fall was increased from 0 in steps of 1 inch.

b. Energy of last impact of series. Tests made with 0.497 lb ball and with edges of the specimens supported on a 3.5 inch pipe cap.

c. Cracked by impact of 2.98 in.-lb in 6 in. fall.

d. Cracked by impact of 2.48 in.-lb in 5 in. fall.

TABLE XII.- PROGRESSIVE-REPEATED FALLING-BALL IMPACT TEST ON SIX PHENOLIC MOLDING MATERIALS[a]

Material	Weight of Ball (lb.)	Thickness of Specimens		Energy to Crack Specimen			Energy to Break Specimen		
		Average (in.)	Range (in.)	Average $\left(\frac{\text{in-lb}}{\text{thickness}^2}\right)$	Range $\left(\frac{\text{in-lb}}{\text{thickness}^2}\right)$	No. of Impacts	Average $\left(\frac{\text{in-lb}}{\text{thickness}^2}\right)$	Range $\left(\frac{\text{in-lb}}{\text{thickness}^2}\right)$	No. of Impacts
BM-45	0.497	0.141	0.124-0.151	194	174-226	7-8	245	218-291	9-10
	0.497	0.267	0.265-0.271	162	148-177	21-25	172	163-184	23-26
	1.977	0.266	0.256-0.278	167	151-179	5-7	177	151-200	5-7
BM-120	0.497	0.149	0.139-0.157	165	154-180	7-8	188	177-206	8-9
	0.497	0.316	0.304-0.327	176	167-188	31-38	181	172-193	32-39
	1.977	0.311	0.304-0.319	163	155-177	8	177	155-192	8-9
BM-6260	0.497	0.138	0.133-0.144	202	191-218	7-8	346	288-393	12-14
	0.497	0.270	2.263-0.280	147	139-152	21-22	182	171-194	26-27
	1.977	0.264	0.249-0.280	143	126-160	5	200	177-223	7
BM-250	0.497	0.133	0.129-0.138	227	209-239	8	825	725-885	25-34
	0.497	0.260	0.255-0.265	195	170-214	24-28	440	425-451	59-60
	1.977	0.269	0.259-0.278	154	147-162	5-6	509	460-538	18-20
BM-200	0.497	0.144	0.143-0.146	376	335-397	14-17	1590	1557-1627	65-68
	0.497	0.251	0.249-0.252	205	200-211	25-27			
	1.977	0.263	0.254-0.270	200	190-214	7	1180	1070-1280	35-46
BM-3510	0.497	0.134	0.129-0.139	194	180-209	7	1748	1633-1910	59-66
	0.497	0.257	0.249-0.265	189	184-192	24-26			
	1.977	0.277	0.276-0.279	198	182-208	7-8	1140	1120-1170	43-45

a. Specimens 3-1/2 by 4-1/2 inches were supported at the edges in a wooden frame resting on a 3/8-inch-thick steel plate. A steel ball of the indicated weight was dropped on the center of the specimens from heights increased in intervals of 1 inch. Three specimens were used for each test.

TABLE XIII.- RESULTS OF IMPACT FLEXURE TEST ON SIX PHENOLIC MOLDING MATERIALS

Material	Mean Bulk Factor	Filler	Impact energy required to reduce flexural strength to: 10,000 lb/in^2 (in-lb/thickness^2)	5,000 lb/in^2 (in-lb/thickness^2)
BM-45	2.45	Woodflour	64	70
BM-120	2.58	Woodflour & cotton flock	73	76
BM-6260	3.8	do.	79	85
BM-250	8.0	Asbestos fibers	90	97
BM-200	9.5	Macerated fibre	102	145
BM-3510	14.5	do.	120	138

TABLE XIV.- COMPARISON OF FLEXURAL STRENGTHS OF SPECIMENS FROM FLAT SHEETS AND MOLDED BOXES
(Tests Made at Span-depth Ratio of 8:1)

Materials[a]	Specimens from 1/8-inch-Thick Sheets: Thickness Average (in.)	Thickness Range (in.)	No. of Tests	Flexural Strength Average (lb/in2)	Flexural Strength Range (lb/in2)	S.E.[b] (lb/in2)	V[c] (%)	Specimens from Molded Boxes: Thickness Average (in.)	Thickness Range (in.)	No. of Tests	Flexural Strength Average (lb/in2)	Flexural Strength Range (lb/in2)	S.E.[b] (lb/in2)	V[c] (%)
BM-45	0.141	0.124-0.157	17	11,900	11,100-14,700	±360	12.4[d]	0.131	0.126-0.134	18[e]	11,900	10,200-13,300	±210	7.6
								0.133	0.127-0.140	18[f]	12,400	11,200-14,000	±160	5.7
								0.119	0.111-0.127	21[g]	12,700	10,300-13,800	±170	6.2
								0.127	0.111-0.140	57[h]	12,300	10,200-14,000	±110	6.9
								0.131	0.128-0.135	18	13,800	12,400-15,000	±150	4.6
BM-120	0.162	0.144-0.175	10	14,200	12,600-17,400	±450	10.1[d]	0.131	0.128-0.135	18[e]	13,800	12,400-15,000	±150	4.6
								0.133	0.128-0.140	18[f]	12,500	10,900-14,000	±200	6.8
								0.123	0.117-0.131	21[g]	13,200	12,200-14,300	±130	4.4
								0.130	0.117-0.140	57[h]	13,100	10,900-15,000	±110	6.5
BM-6260	0.139	0.124-0.159	18	11,200	9,300-13,400	±240	9.0	0.138	0.132-0.149	18[e]	10,900	8,200- 12,700	±270	10.4
								0.136	0.131-0.144	18[f]	11,600	9,300-13,300	±230	8.5
								0.120	0.113-0.127	18[g]	11,800	9,200-13,600	±320	11.3
								0.131	0.113-0.149	54[h]	11,500	8,200-13,600	±160	10.5
BM-250	0.136	0.120-0.145	18	12,600	9,300-15,100	±400	13.6	0.139	0.130-0.149	16[e]	6,980	6,000- 8,300	±160	9.4
								0.140	0.129-0.145	18[f]	8,590	6,700-10,500	±270	13.5
								0.117	0.109-0.124	20[g]	8,210	5,000- 9,600	±300	16.1
								0.131	0.109-0.149	54[h]	7,970	5,000-10,500	±170	16.0
BM-200	0.144	0.140-0.146	12	12,100	8,800-16,200	±600	17.3	0.133	0.130-0.136	18[e]	12,100	8,300-15,200	±400	13.9
								0.135	0.130-0.143	18[f]	11,800	9,200-17,800	±430	15.4
								0.120	0.114-0.128	20[g]	14,700	11,500-18,600	±380	11.7
								0.129	0.114-0.143	56[h]	13,000	8,300-18,600	±290	16.7
BM-3510	0.134	0.124-0.143	12	12,000	9,200-15,900	±600	17.5	0.132	0.128-0.137	18[e]	12,400	8,600-14,800	±320	11.8
								0.135	0.130-0.143	17[f]	12,900	10,500-14,600	±310	9.8
								0.129	0.124-0.138	21[g]	14,000	10,200-17,800	±440	14.3
								0.132	0.124-0.143	56[h]	13,200	8,600-17,800	±230	13.3

a. Materials are listed in order of increasing bulk factors.
b. S E. = standard error of the mean.
c. V = coefficient of variation.
d. Warping of sheets of BM-45 and taper of sheets of BM-120 may be the cause of the higher variation in the flat sheet as compared with the boxes.
e. Specimens from sides of boxes with long axis perpendicular to bottom.
f. Specimens from sides of boxes with long axis parallel to bottom.
g. Specimens from bottoms of boxes lengthwise and crosswise.
h. Composite of all specimens from boxes.

TABLE XV.- STRENGTH TESTS ON MOLDED BOXES

Material	Batch No.	Loading at Molded Hole[a]			Loading at Point on Bottom of Box Symmetrically Located with Respect to Molded Hole					
					Without Rubber Cushion			With Rubber Cushion[b]		
		No. of Tests	Breaking Load Average (lb.)	Breaking Load Range (lb.)	No. of Tests	Breaking Load Average (lb.)	Breaking Load Range (lb.)	No. of Tests	Breaking Load Average (lb.)	Breaking Load Range (lb.)
BM-45	182A	3	98	88-108	3	75	75- 76	3	200	181-214
BM-120	744C	3	121	114-132	3	84	82- 87	3	188	184-190
BM-6260	1221	3	113	108-120						
	1359				3	81	79- 83	3	211	192-242
BM-250	202D	3	147[c]	132-160	2	172[c]	144-200	3	230[e]	226-238
	207H	3	129[d]	122-133	3	112[d]	104-122			
BM-200	27	3	213	206-220	2	218	172-244			
	23							1	298	
BM-3510	1985	3	249	232-282	3	274	252-290			
	2112	3	203	198-206				3	353	322-374

a. Boxes were loaded at the indicated points with a plunger having a hemispherical end of 5/8-inch radius. Rate of head travel was 0.05 inch/minute.
b. Rubber cushion consisted of a No. 7 rubber stopper placed with larger face next to box.
c. Boxes had numerous small cracks in a variety of locations. Boxes were cooled before ejection.
d. Boxes were cured at 320 F for 5 minutes and ejected hot. This improved the appearance of moldings.
e. Boxes were molded at a later date than the others of this batch.

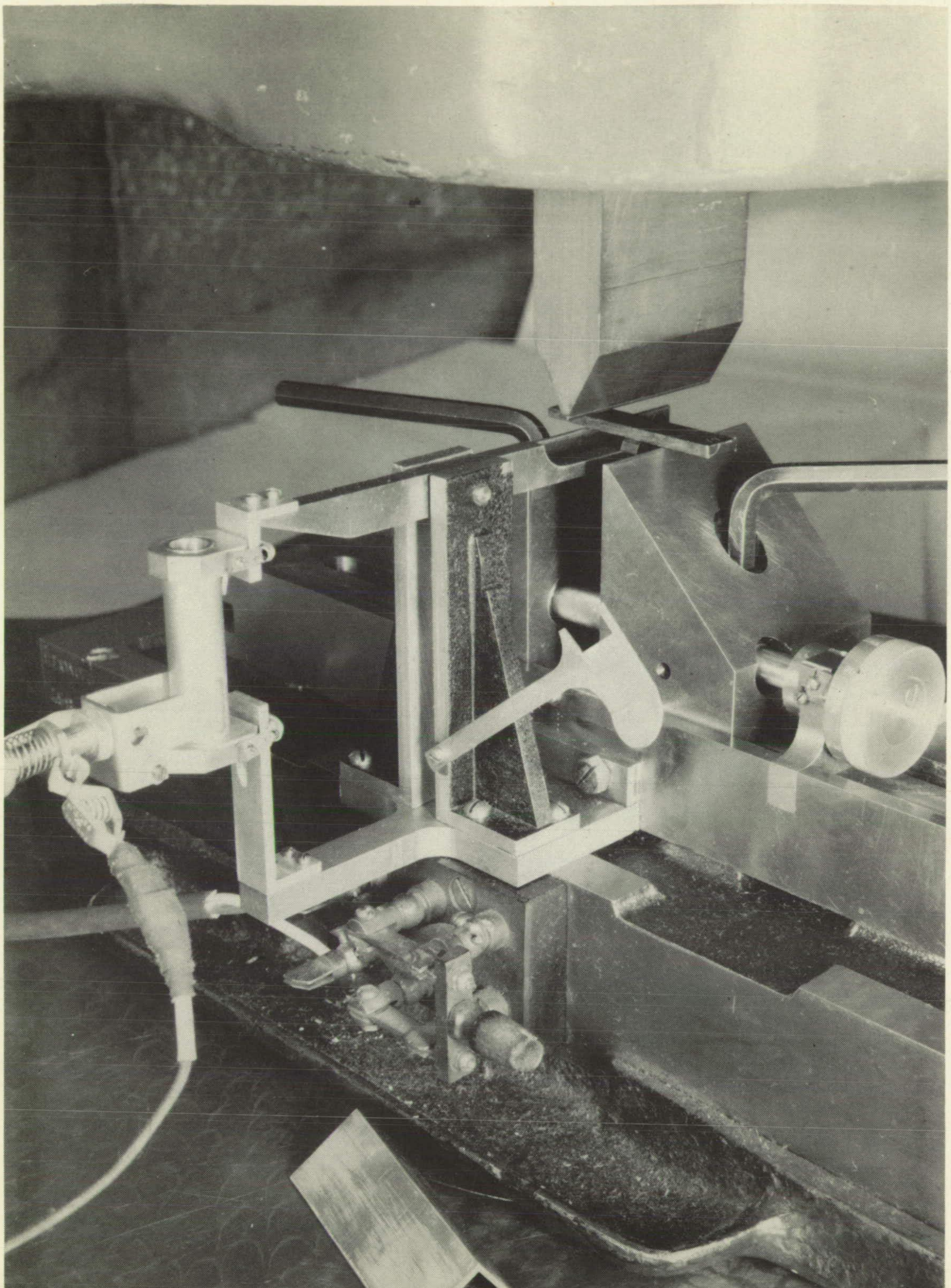


Figure 1.- Flexure-test jig.

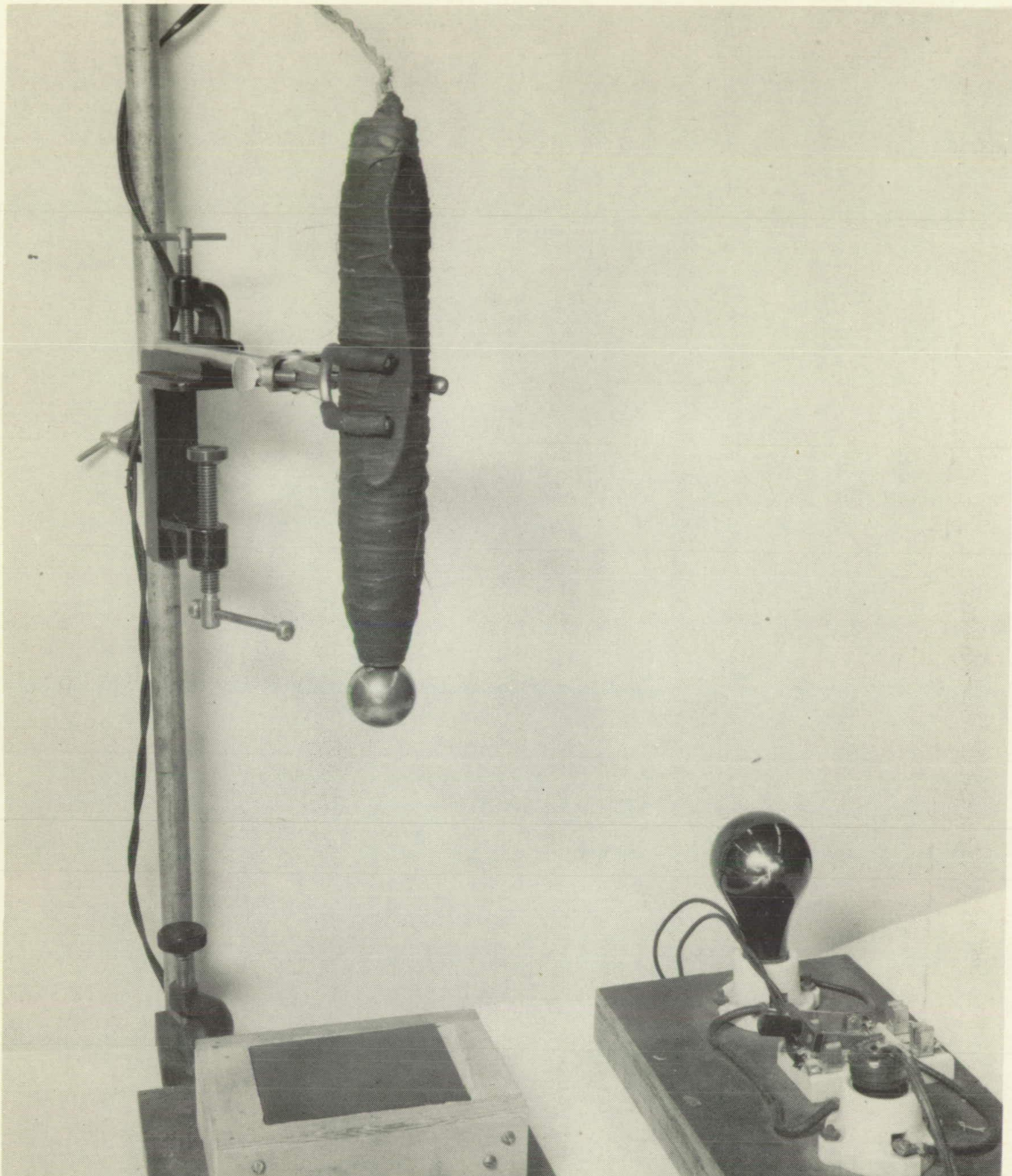


Figure 2.- Apparatus for falling-ball impact test.

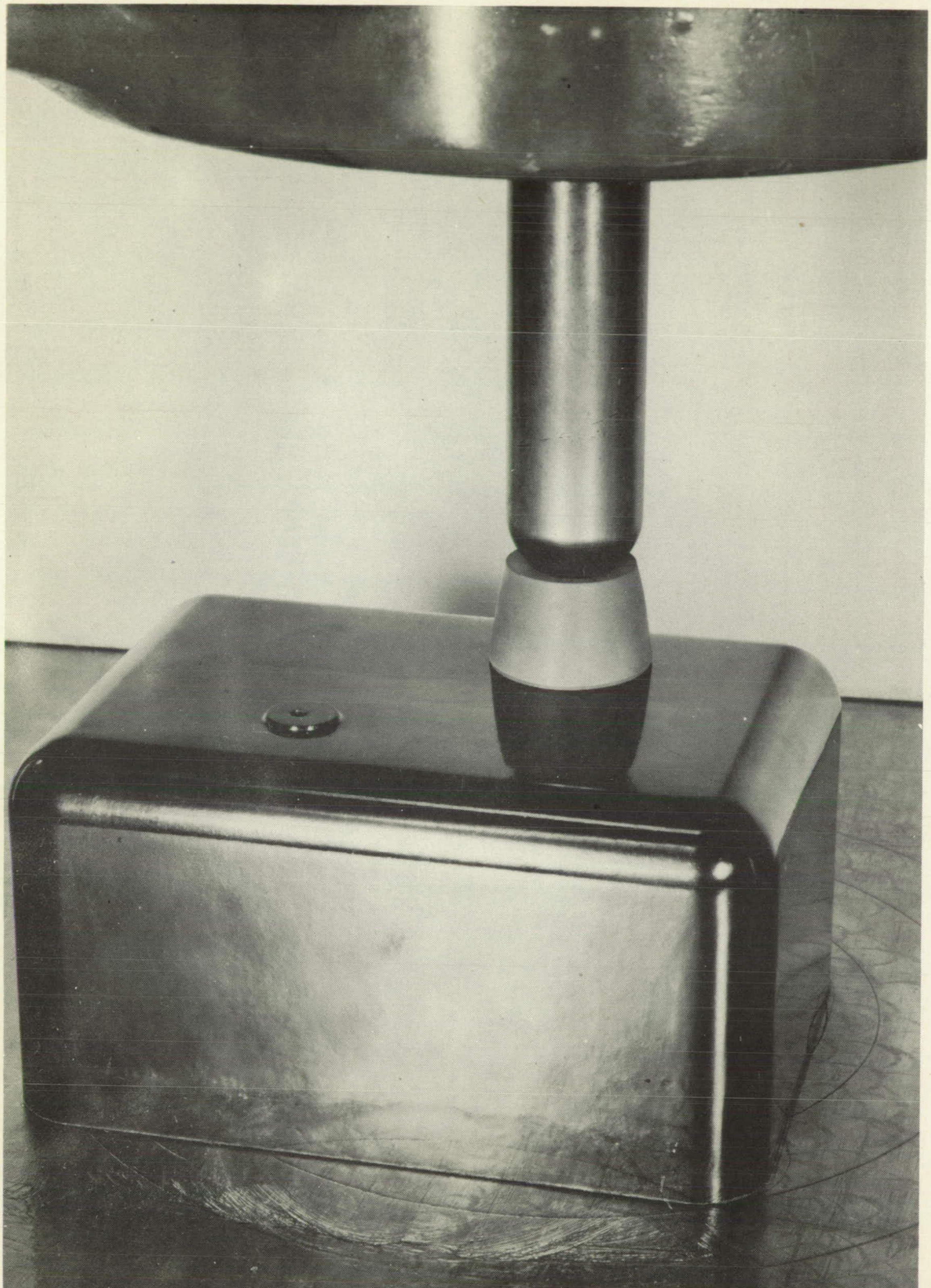
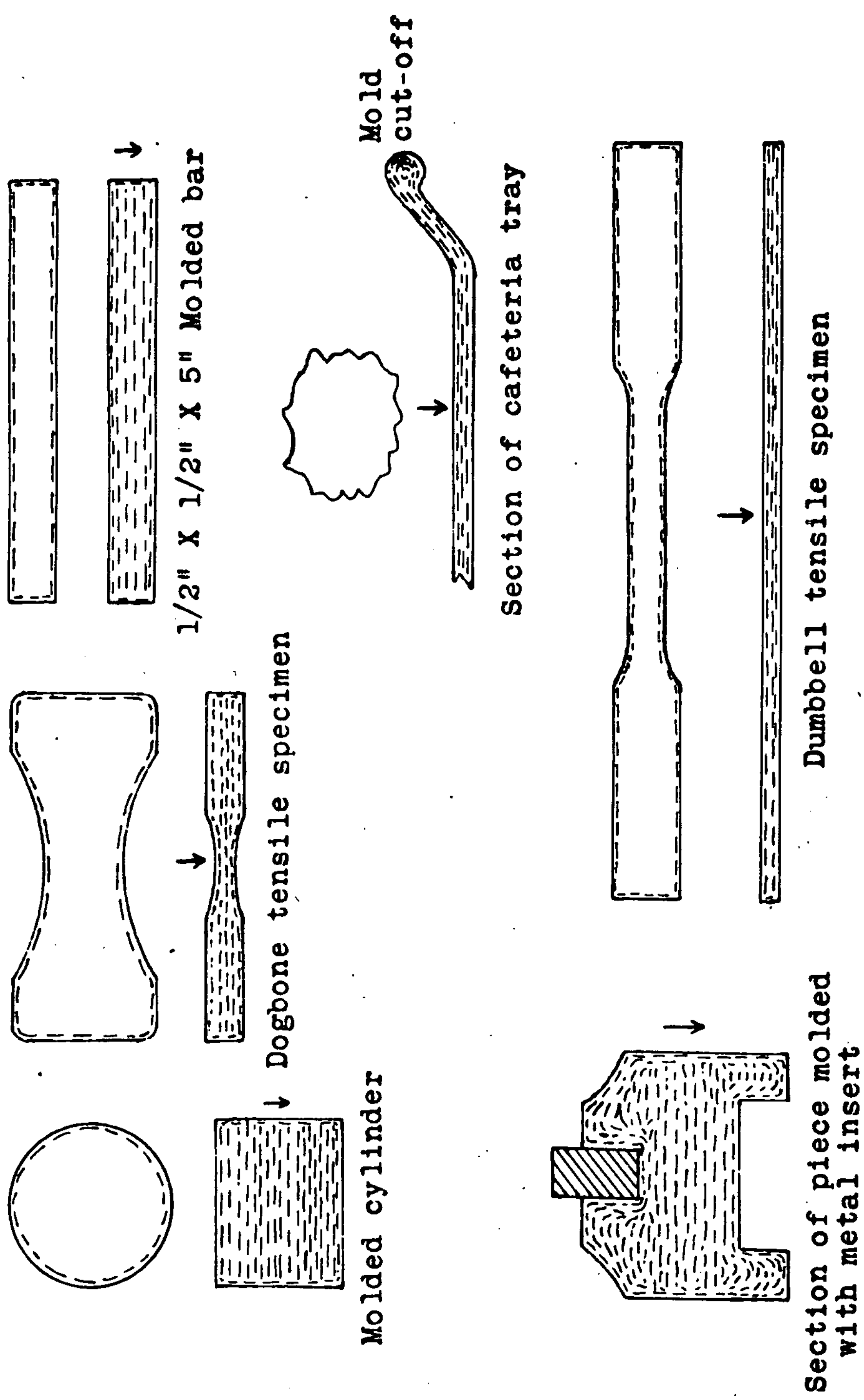


Figure 3.- Breaking strength tests on molded boxes.



External arrows indicate direction of molding ram motion.
Clear areas indicate random orientation.

Figure 4.- Typical orientations of fibrous fillers in special molded shapes.

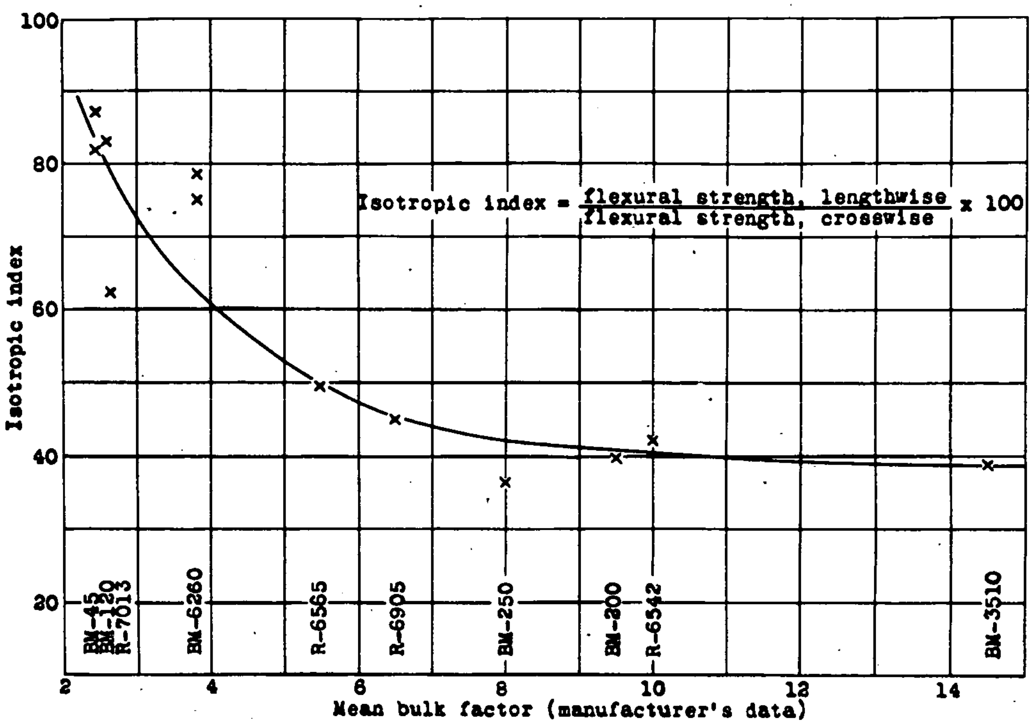


Figure 5.- Anisotropy of 2-inch cylindrical moldings.

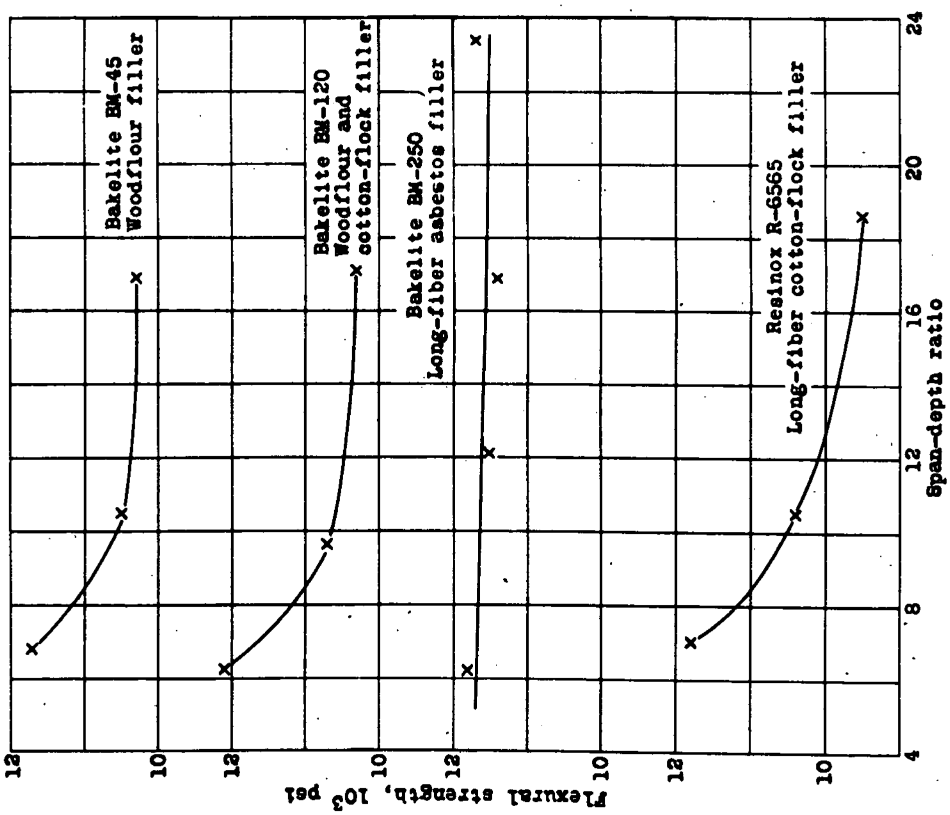


Figure 6.- Variation of flexural strength with span-depth ratio.

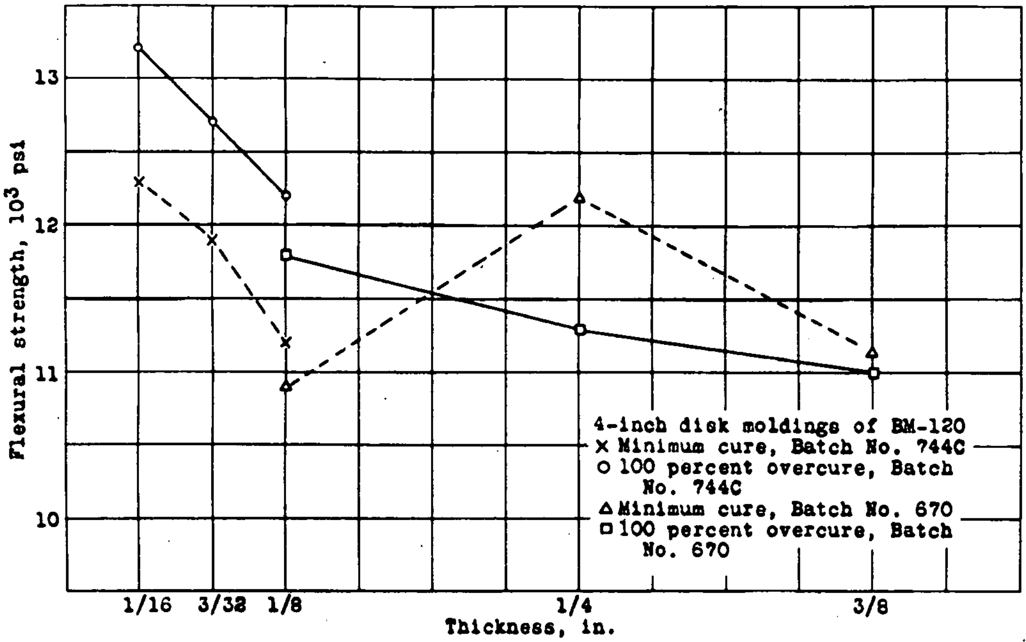


Figure 7.- Variation of flexural strength with thickness and cure of moldings.

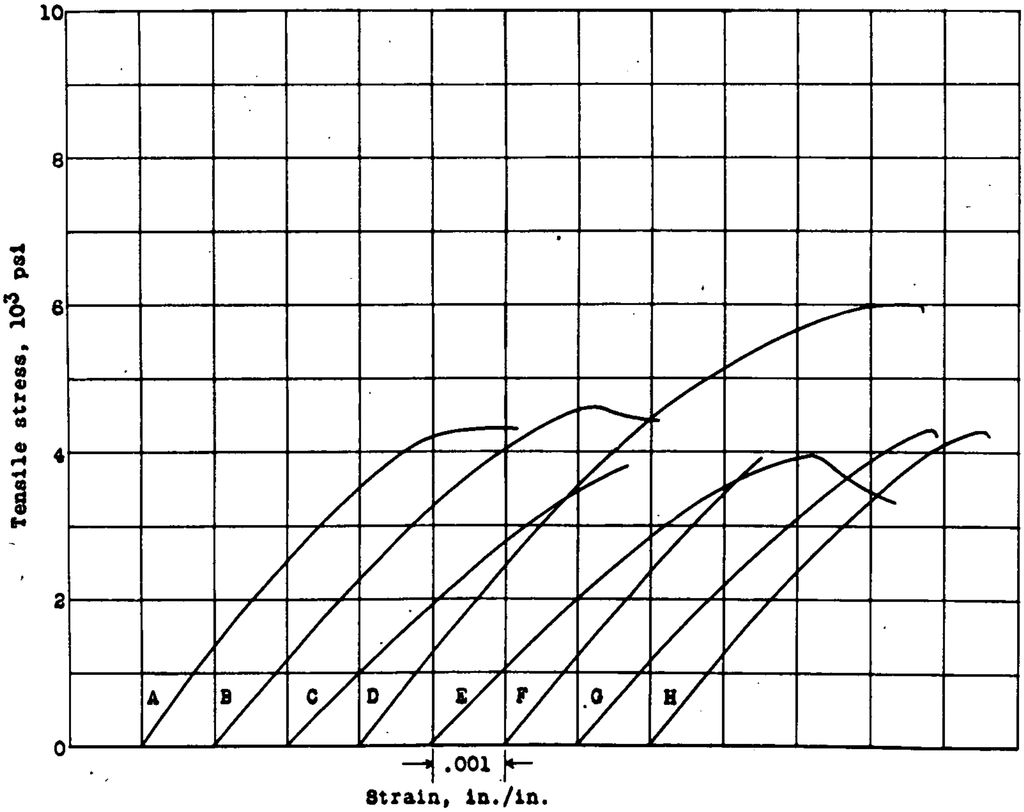


Figure 8.- Tensile stress-strain diagrams for individual specimens of Resinox 6905

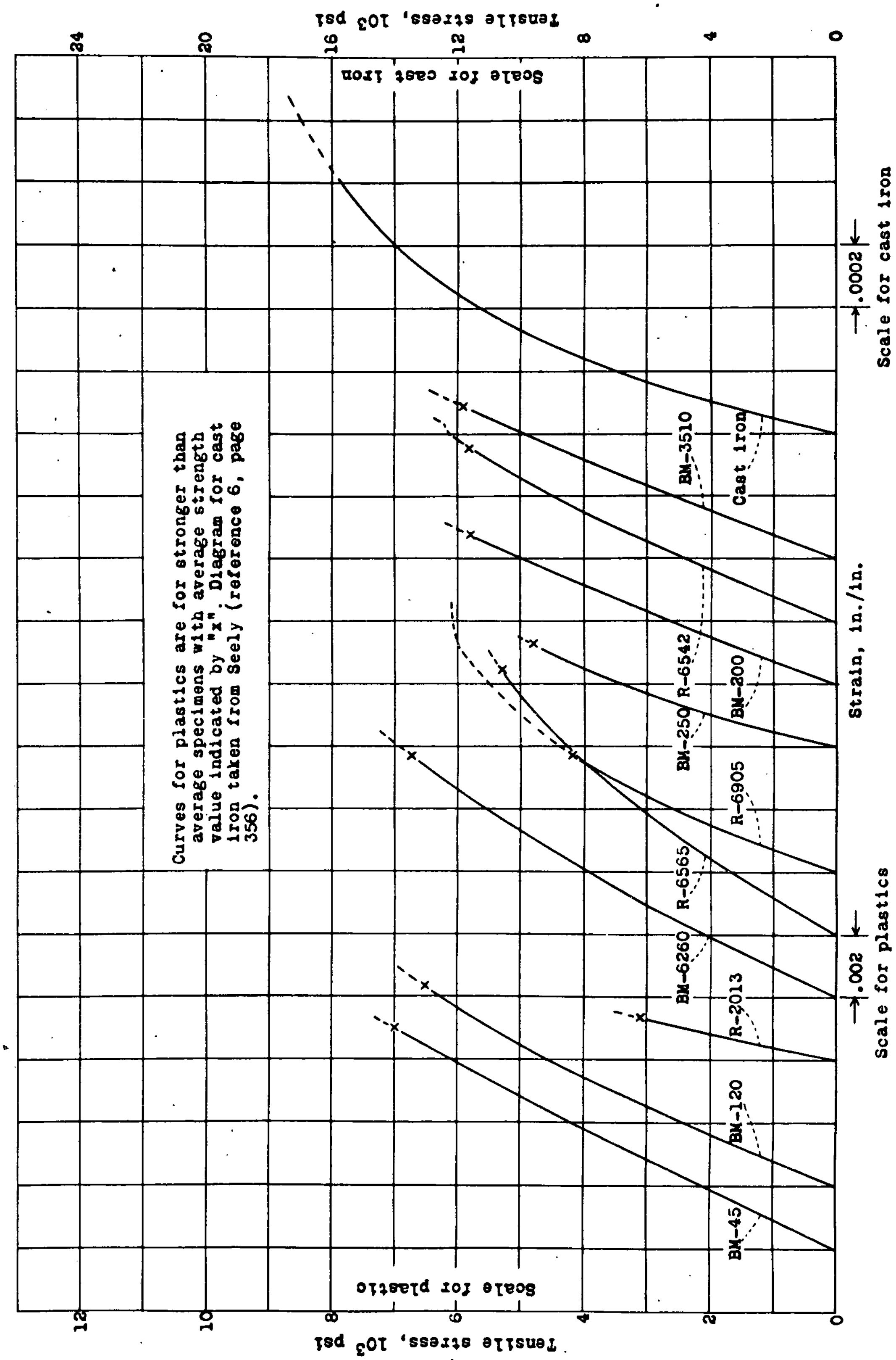


Figure 9.- Typical tensile stress-strain diagrams for molded phenolic tensile specimens and cast iron.

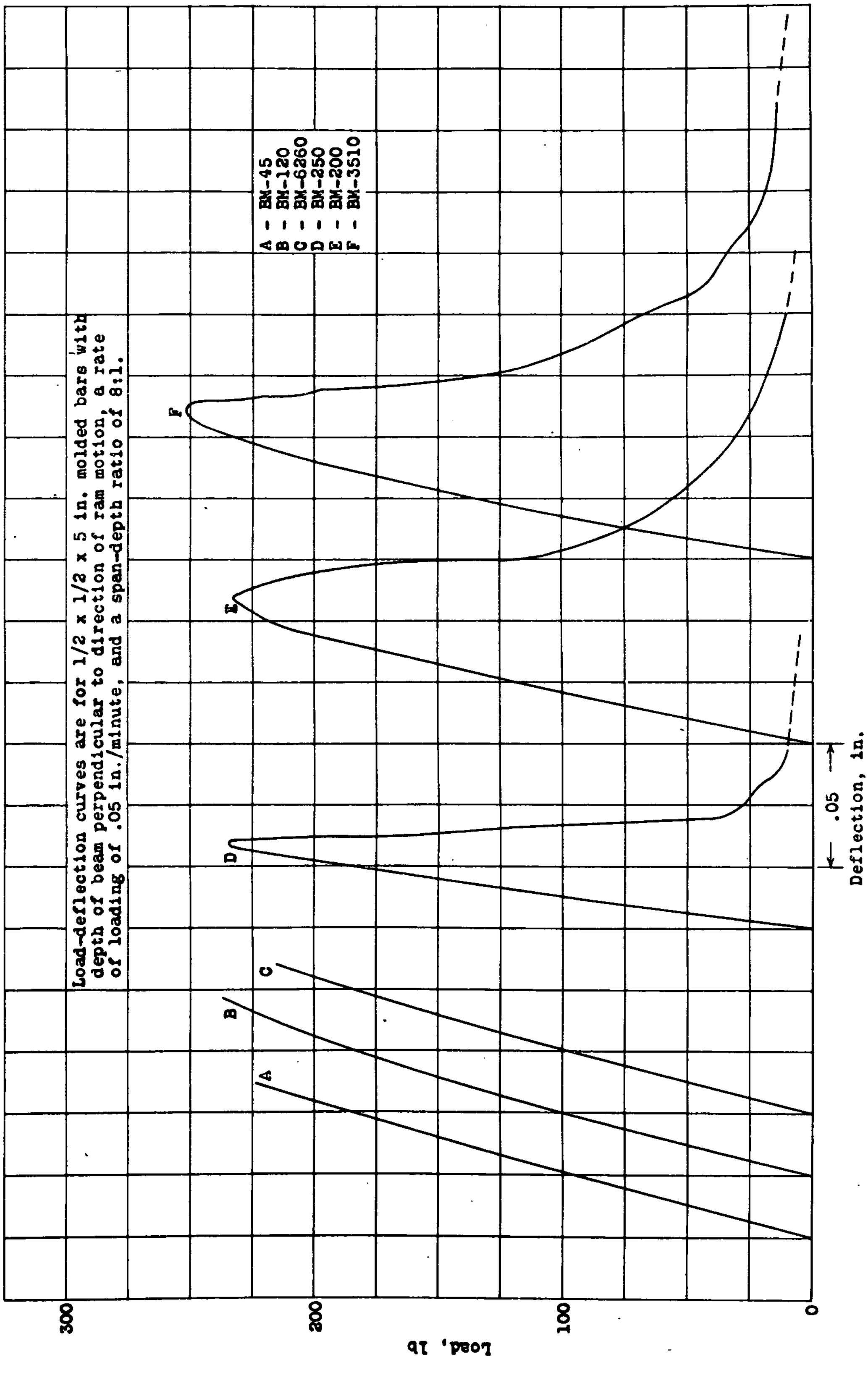


Figure 10.- Typical load-deflection curves for molded phenolic materials.

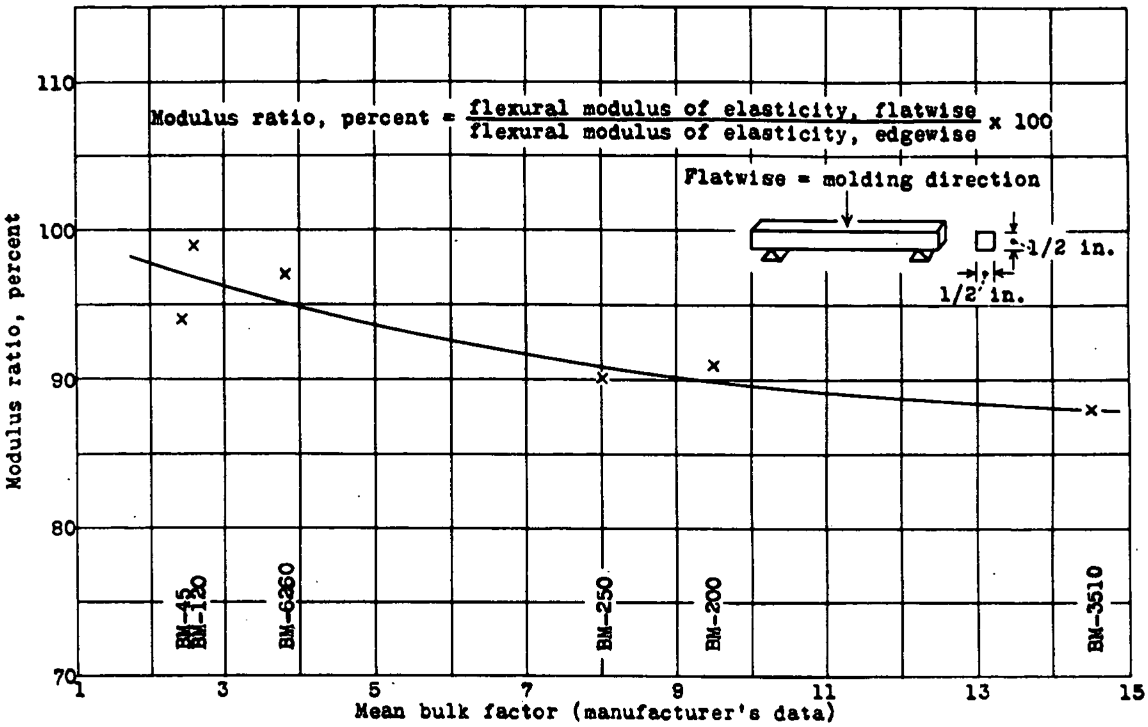


Figure 11.- Effect of direction of molding pressure on flexural modulus of elasticity of molding powders with various bulk factors.

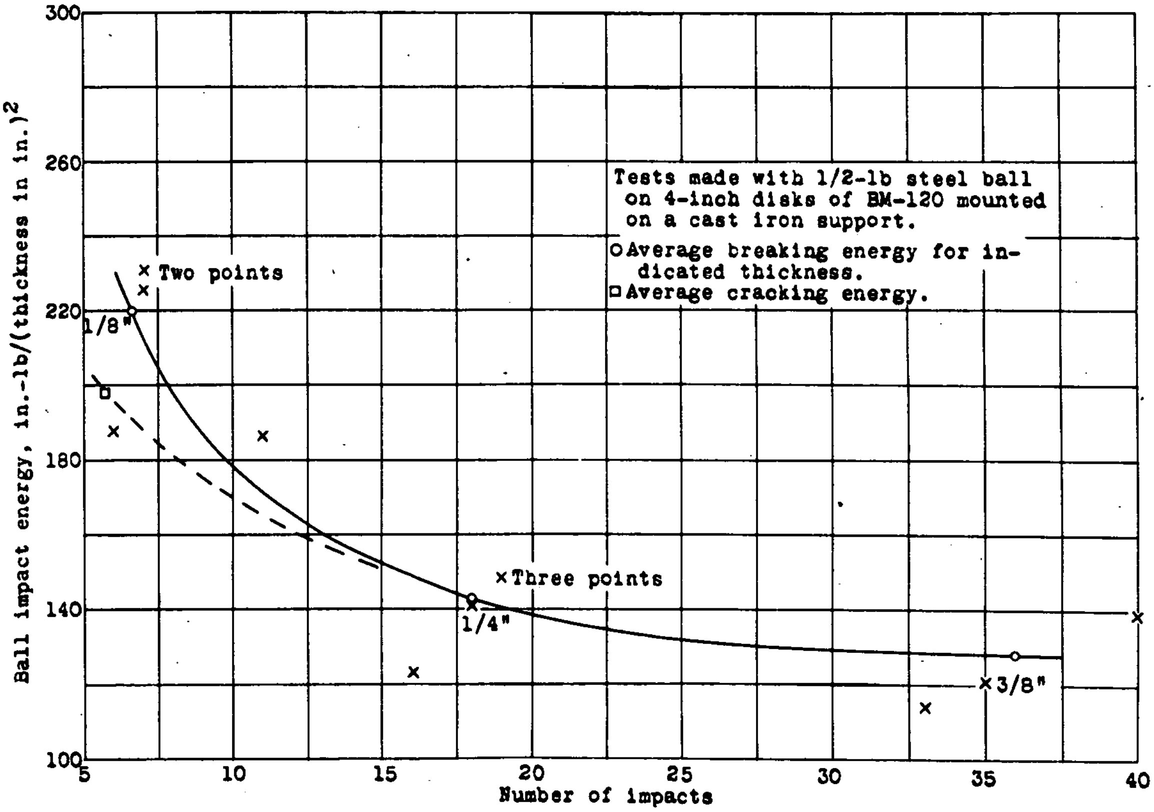


Figure 12.- Relation of energy of final impact to break in ball impact test to number of impacts.

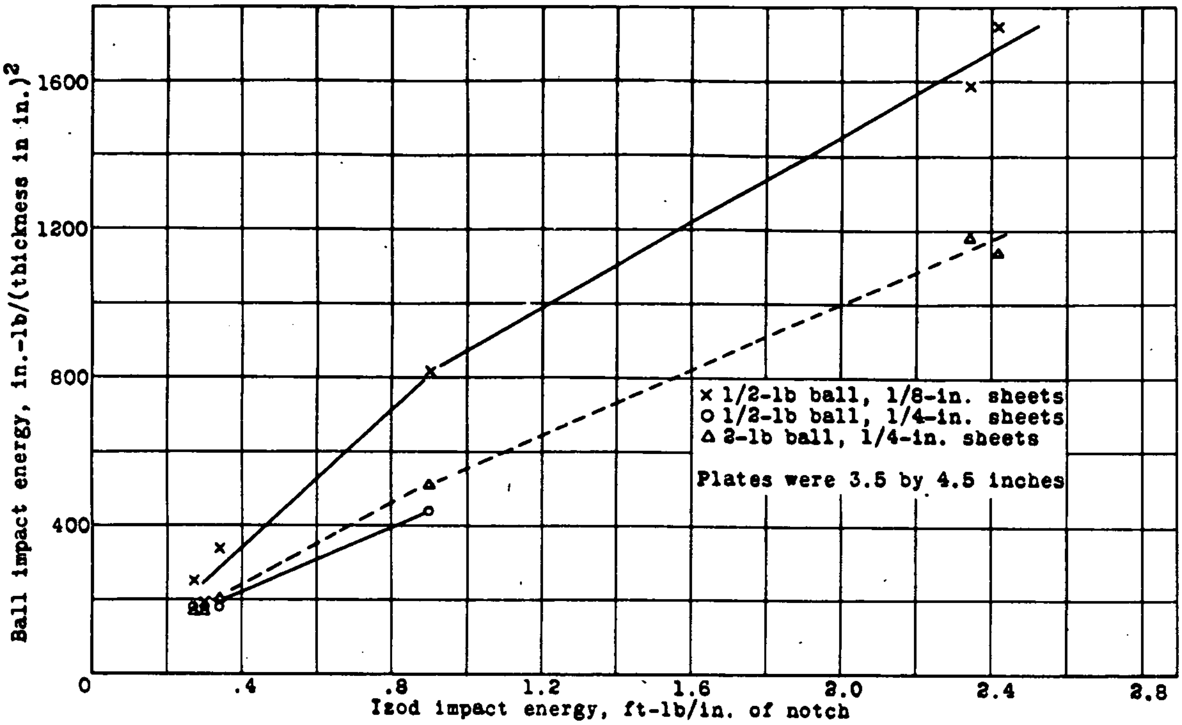


Figure 13.- Comparison of energy of final impact to break plates in falling ball impact test and Izod impact strength.

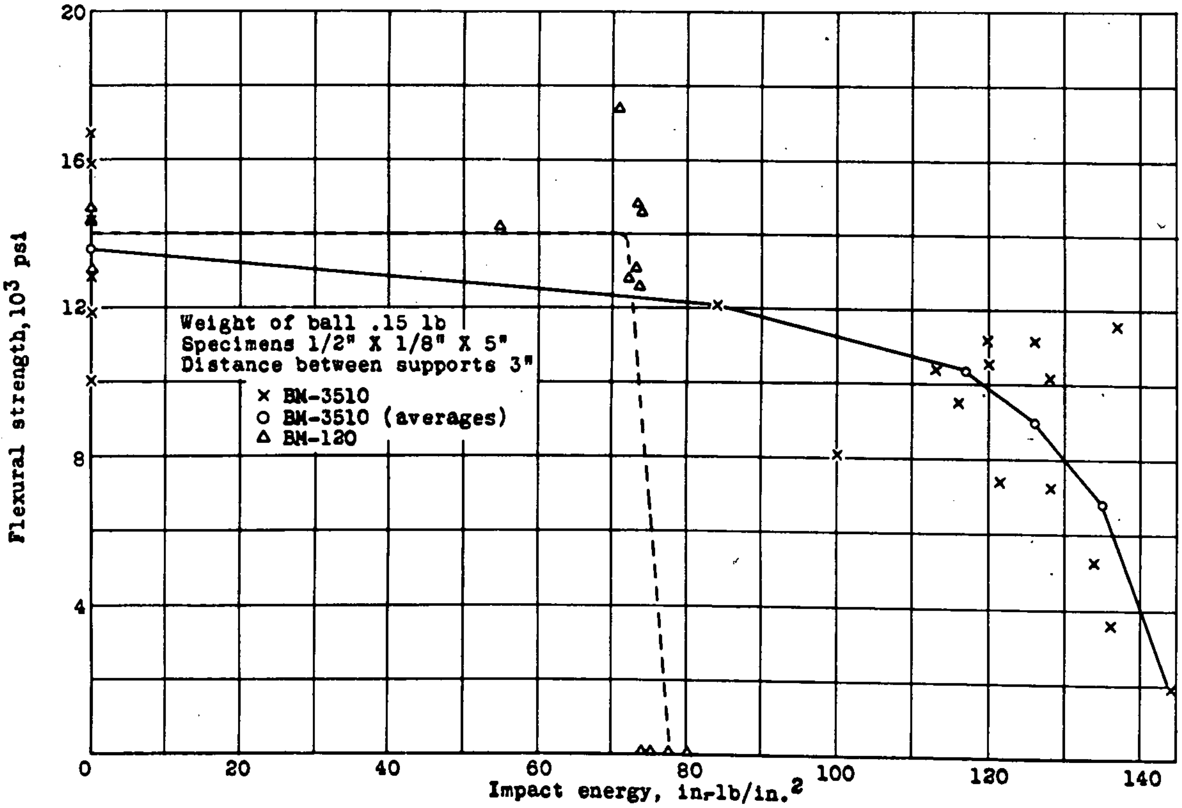


Figure 14.- Effect of single falling-ball impacts on flexural strength.

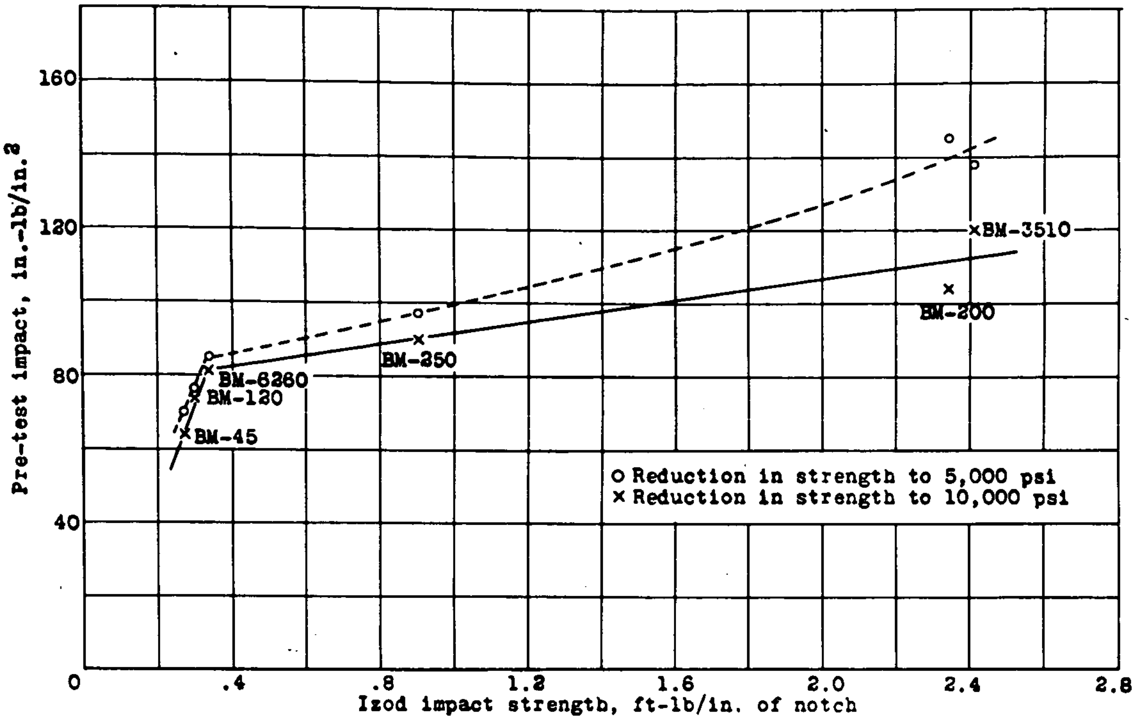


Figure 15.- Relation between single blow impact energy required to reduce average flexural strength to a selected value and the Izod impact of phenolic molding materials.

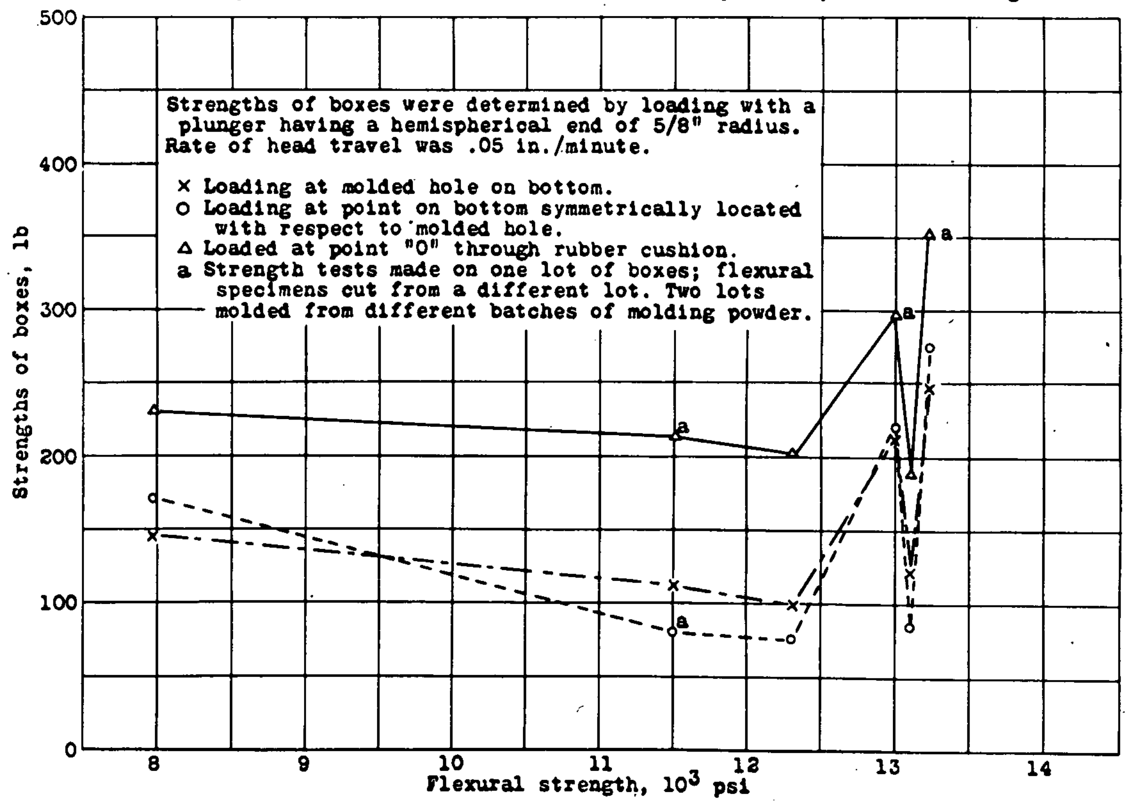


Figure 17.- Strengths of boxes compared with flexural strengths of specimens from boxes.

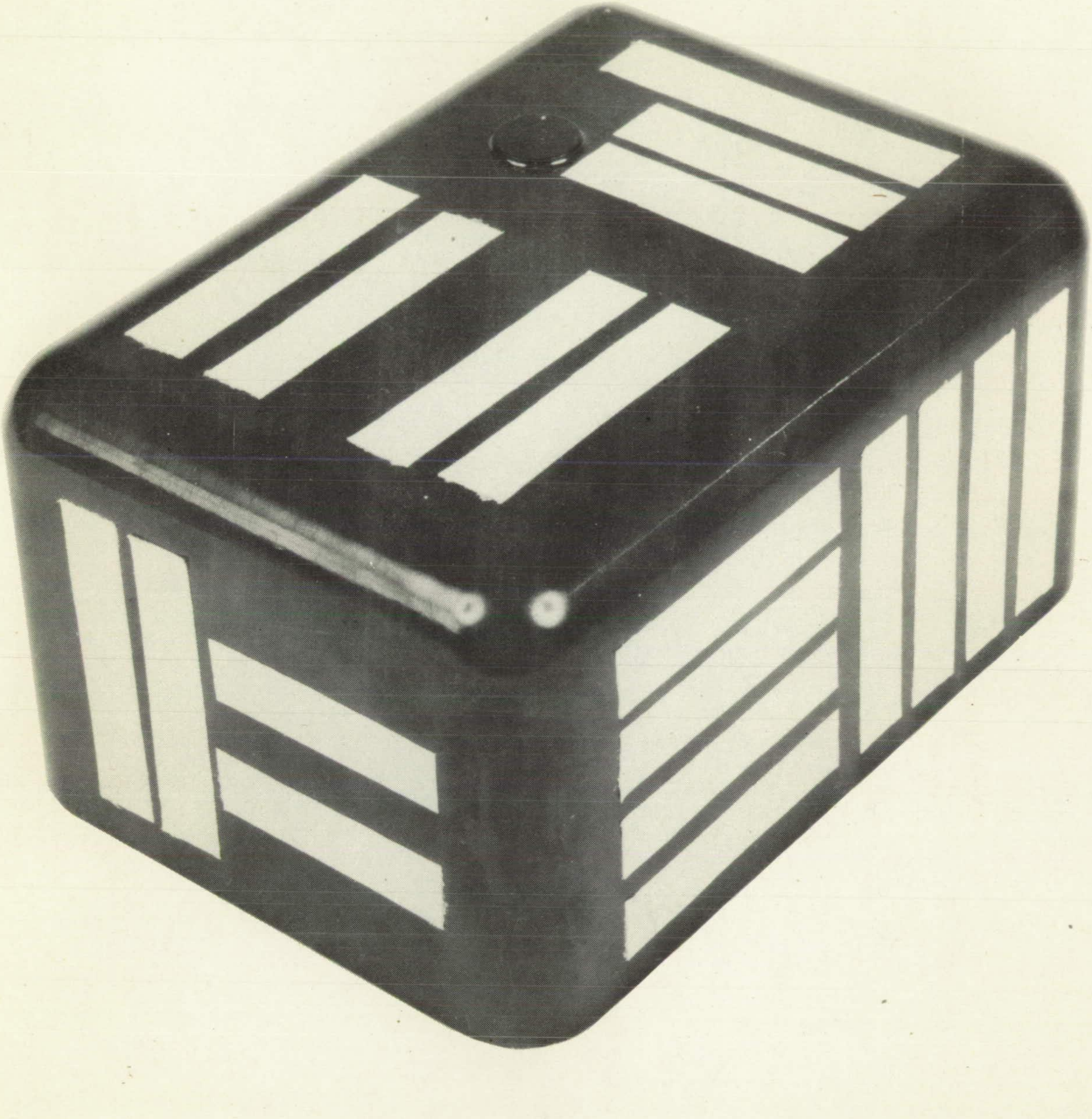


Figure 16.- Locations of specimens cut from molded boxes.

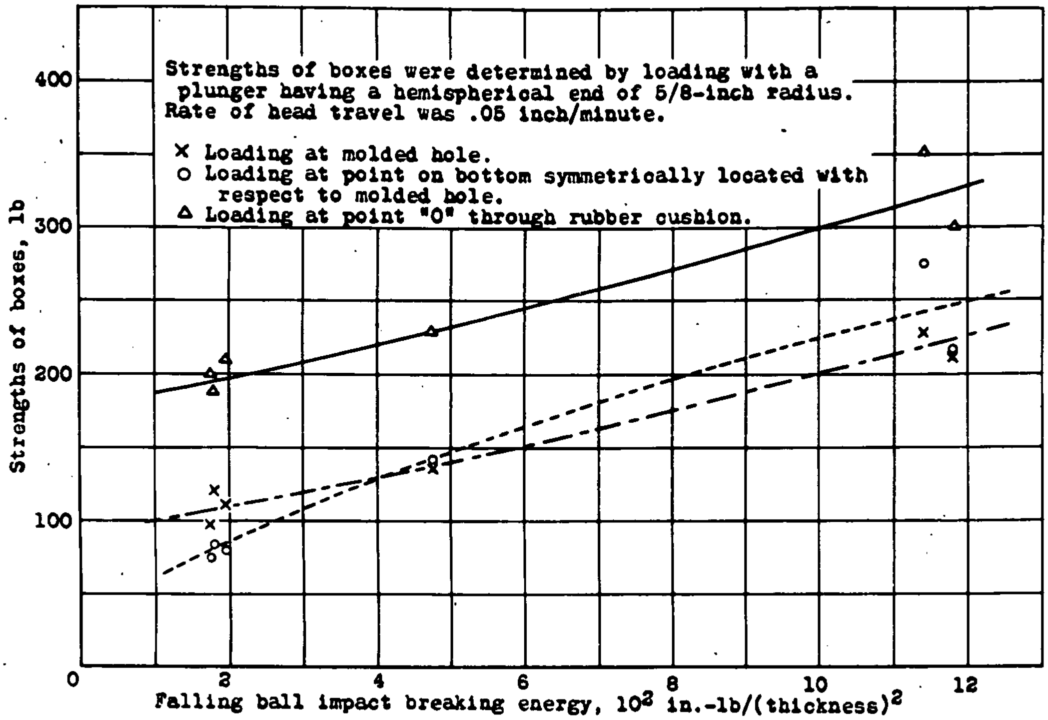


Figure 18.- Strengths of boxes compared with results of falling ball impact test on 1/4-inch-thick flat sheets.

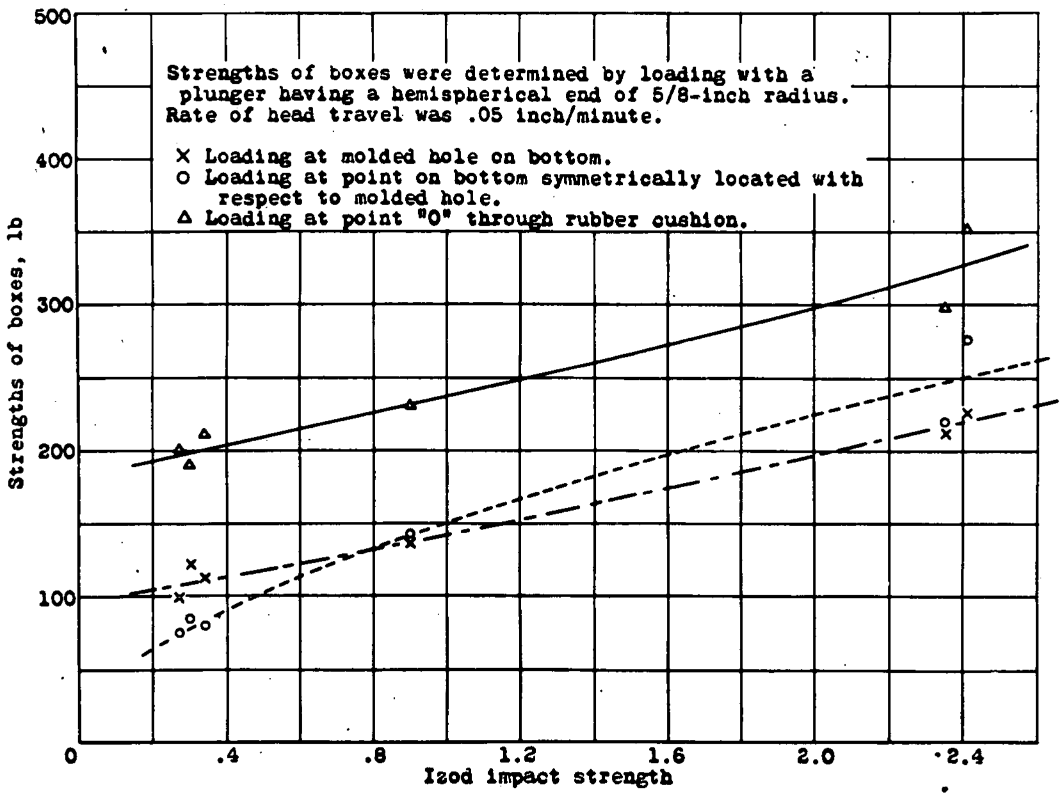


Figure 19.- Strengths of boxes compared with Izod impact strengths.

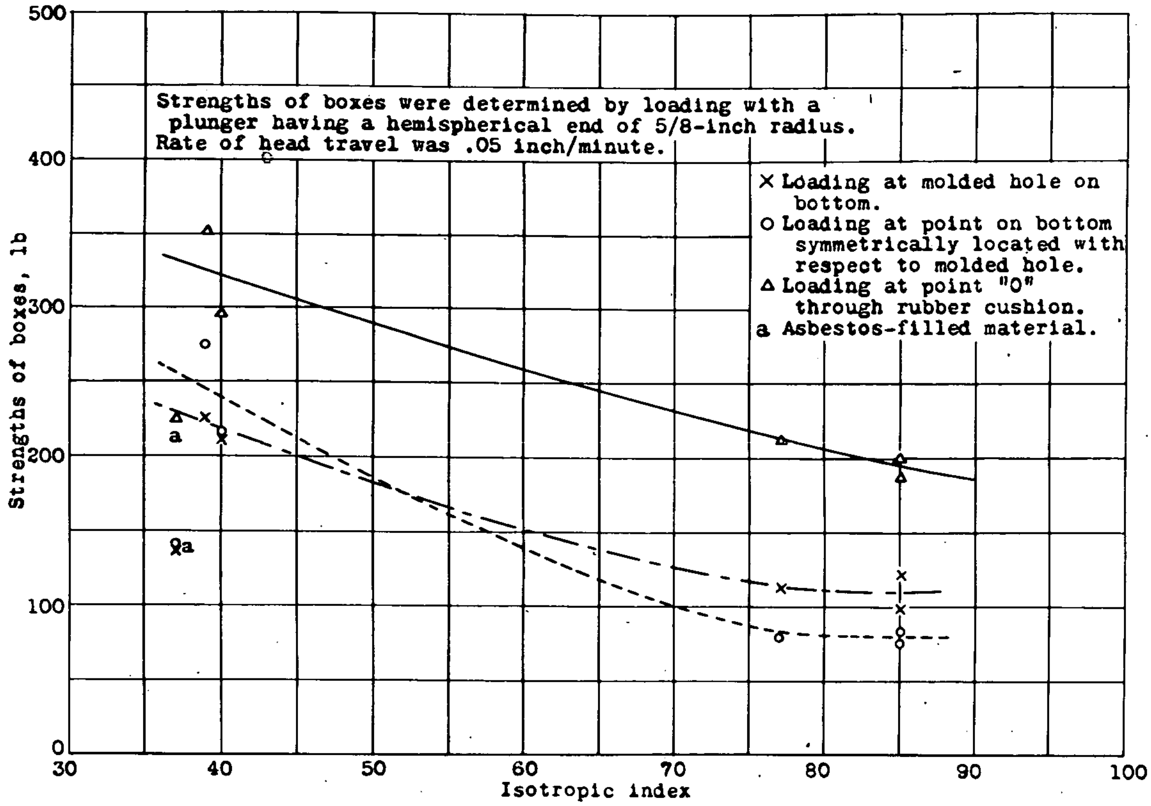


Figure 20.- Strengths of boxes correlated with Isotropic index.

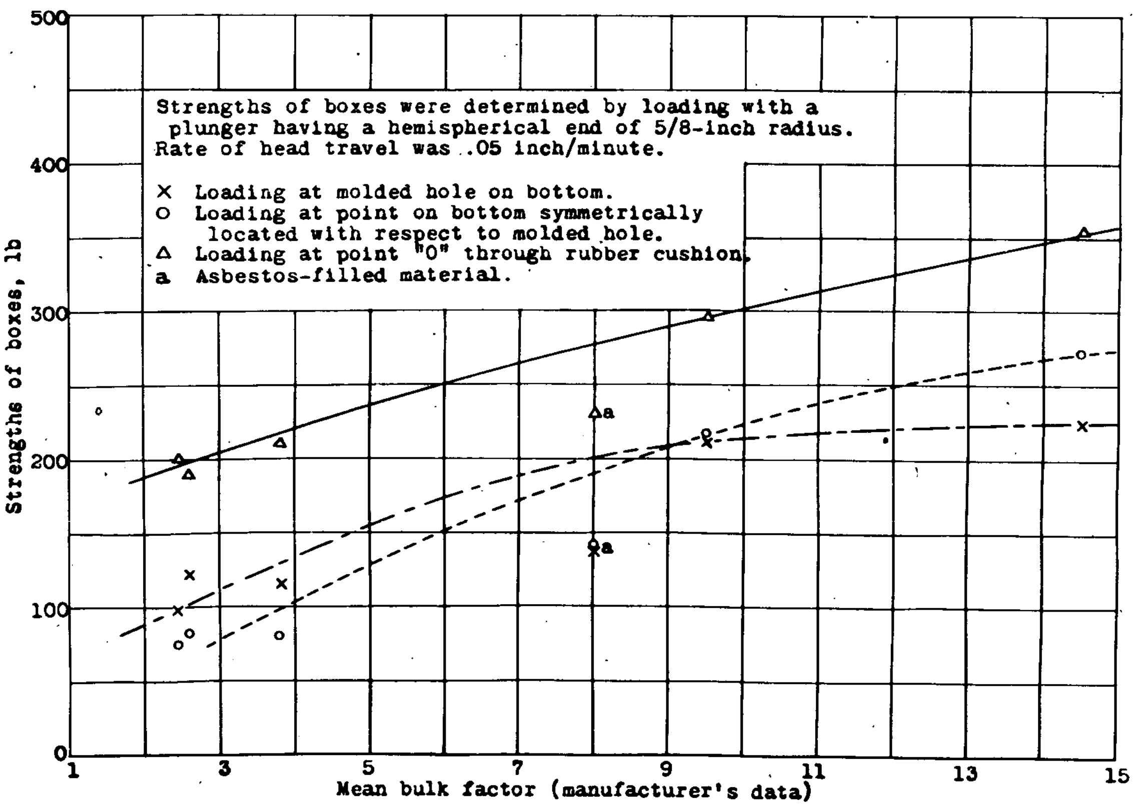


Figure 21.- Strengths of boxes correlated with bulk factors of powders.

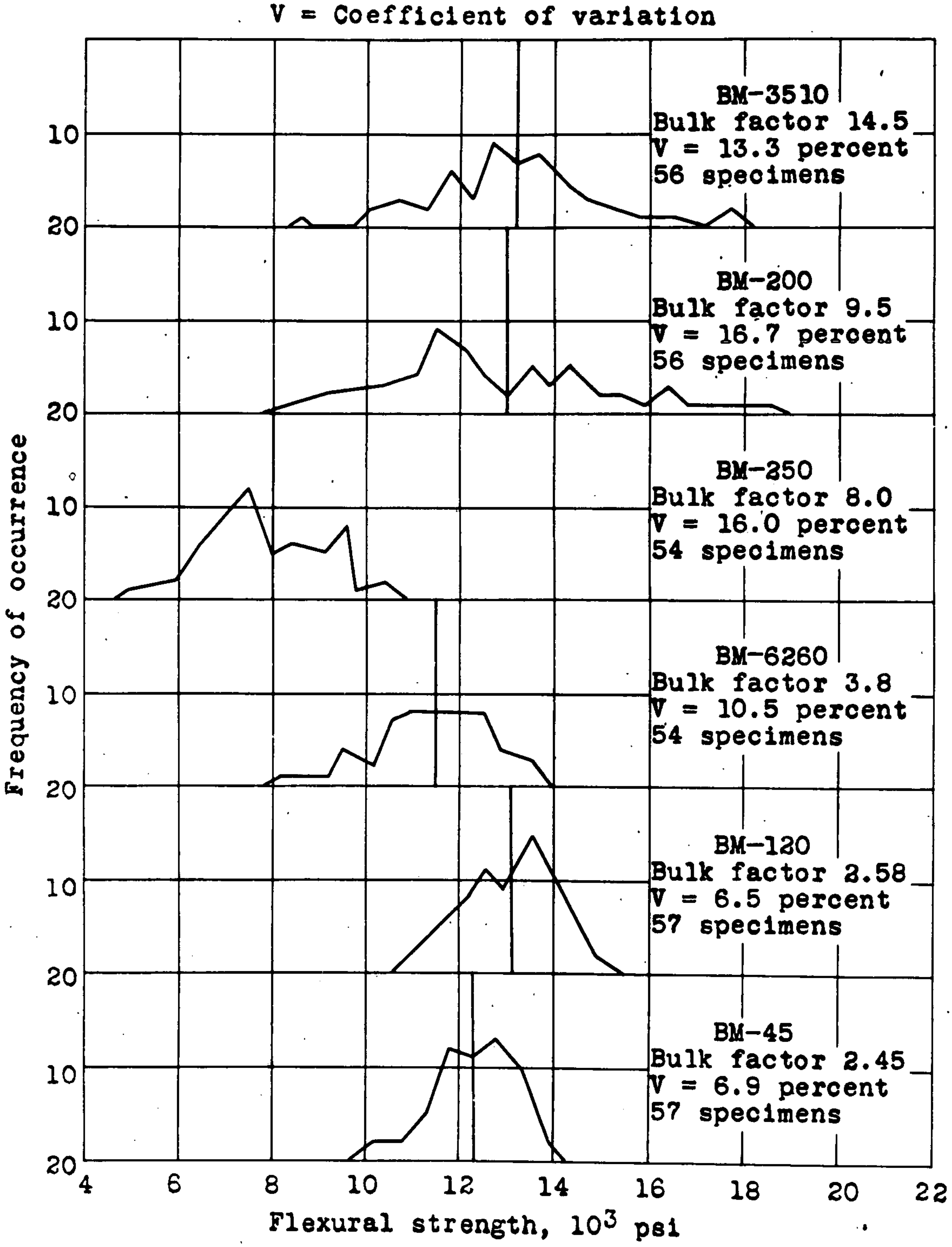


Figure 22.- Frequency-flexural strength diagrams, specimens from boxes.